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Tree Ferns of Central Veracruz: Harvest and Conservation Implications

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Tree Ferns of Central Veracruz: Harvest and Conservation Implications

by

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Dedication

To my wife Ingrid, for all of her unconditional love and support. Thank you Tututcha.

To my mother Inés and my brother Guillermo. This work is also theirs.

To my father and his 6 victories.

To Brigid and Bernhard, for all their help and insistence.

I love you all. Los amo a todos.

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Thanks to The University of Texas at Austin, Hook ‘em horns!

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Abstract

Tree Ferns of Central Veracruz: Harvest and Conservation Implications

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Tree ferns are listed as endangered species under Mexican law and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Despite this status, tree ferns are currently being harvested by rural communities, and sold in the form of handicrafts, traditional medicines, and household ornaments In the state of Veracruz, some authors argue that the harvesting of tree fern caudexes (trunks) to obtain a material made out of the fern's adventitious roots called *maquique* poses a major threat to tree fern conservation. This thesis systematically explores the effect of harvesting activities on the distribution of tree fern species in the tropical montane cloud forest's fragmented landscape using vegetative regeneration as a proxy for *maquique* harvesting. The study was conducted in El Zapotal in the municipality of Acajete and El Riscal in the municipality of Coatepec, two small

communities with different land use histories. A census was performed at each site to georeference and document all tree fern individuals, including information on diameter, height and presence/absence of vegetative regenerations due to *maquique* harvesting per individual tree fern. Four species were present in the study: *Alsophila firma, A. tryoniana, Cyathea bicrenata*, and *C. fulva*. ArcGIS Desktop was used to calculate distances from individual tree ferns to trails and rivers, which were regarded as points of access for *maquique* harvesters. These data were used to infer how and whether *maquique* affects the distribution and abundance of tree fern species at the two studied sites.

This study reports for the first time different forms of vegetative regenerations in Mexican tree fern species such as the resprouting of multiple branches from a single tree fern trunk and also documents different forms of harvesting like the “C cut”. Contrary to common conservation arguments, the study shows that tree ferns can continue to thrive even after a severe environmental modification, such as forest clearing and the establishment of tree plantations. Other results suggest that *maquique* harvesters operating clandestinely are more likely to target tree ferns with *maquique* closer to points of access (trails or rivers) rather than according to size. In the long run, this pattern of tree fern harvesting could modify the distribution of tree ferns as they are displaced from areas closer to human access, despite the ability of some tree fern species to regenerate in highly disturbed environments.

The discovery of tree fern regenerative properties offers potential for the management of certain tree fern species as umbrella species for conservation in central Veracruz. It suggests that *maquique* harvesting might be sustainable given careful management and government regulation based on scientific data.

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Introduction

Tree ferns have been extensively studied in Mexico and other countries, mainly in taxonomic or other botanical contexts (Conzatti 1939, Lira and Riba 1984, Matuda 1956b, Matuda 1956a, Mickel and Beitel 1988, Pacheco and Lorea-Hernández 1985, Palacios-Ríos 1992a, Palacios-Ríos 1992b, Palacios-Ríos and Gómez-Pompa 1997, Pérez-García and Riba 1994, Riba 1981, Riba 1993, Vázquez-Domínguez 2001). However, few studies have analyzed this group of plants from the perspective of non-timber forest products (NTFP). The present study systematically explores the effect of the harvesting activities on the distribution of tree fern species in the tropical montane cloud forest's fragmented landscape. Tree ferns (Pteridophyta) are a group of vascular plants with high biological and conservation importance and are considered to be indicators of areas with little or no anthropogenic disturbance in tropical montane cloud forests (TMCF) (Palacios-Ríos and Flores 1992, Palacios-Ríos 1997). Tree ferns are listed as endangered species under Mexican law and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (Palacios-Ríos 1997). Despite this status, tree ferns are currently being harvested by rural communities, and sold in the form of handicrafts, traditional medicines, and household ornaments (Palacios-Ríos and Flores 1992, Palacios-Ríos 1997, Palacios-Ríos and Mehltreter 1999).

Tropical montane cloud forest is the principal habitat of tree fern species in Mexico and is one of the most biodiverse and most threatened ecosystems in the country, constituting a mere 0.9 percent of all of forested areas (Ricker *et al* 2007). The largest remaining area of TMCF in Mexico is located in the state of Veracruz, between 1200 and

2100 meters altitude (Williams-Linera 2007), where topographic variation and micro-environmental heterogeneity characteristic of the sierras results in different composition and structure between relatively close fragments of TMCF, most of which are located in a matrix of family farms, coffee plantations, and urban areas (Williams-Linera 1993). The conversion of TMCF to other land uses is occurring rapidly, with only 10 percent of the original forest remaining (Williams-Linera 2007). In this context, the major concerns regarding tree fern species' conservation are habitat loss and harvesting of tree ferns.

This research assesses the impacts of current tree fern harvest practices based on population structure and regeneration, as well as habitat loss. The study was conducted in rural communities of central Veracruz, Mexico, specifically in the municipalities of Coatepec and Acajete. To evaluate the effect of harvesting on tree fern populations, the natural regeneration of the harvested tree ferns populations was analyzed in relationship with proximity to access points such as trails and rivers nearby the study sites. This was achieved by conducting an inventory of all tree ferns by species, including ferns resprouted from stumps and newly sprouted ferns. Using GIS software, distances from individual tree ferns to access points were mapped. The relationships between tree fern size, harvesting, regeneration patterns, and proximity to access points were analyzed to investigate the implications of harvesting for the conservation of tree fern populations.

Chapter 1: Non-Timber Forest Products, Land Use, and Land Use Change

NON-TIMBER FOREST PRODUCTS

What is a non-timber forest product?

Non-timber forest products (NTFPs) are described in various ways. Authors may refer to NTFPs as wild products, natural products, non-timber forest and grassland products, veld products and sustainably produced wood products, secondary, minor, special or specialty non-wood, or non-traditional products (Belcher 2003). However, none of these descriptions is fully accurate and this is cause for debate on the definition of non- timber forest products. Nevertheless, it is generally agreed that NTFPs are products generated from the forest that are not timber-based, more specifically, plants and parts of plants that are harvested from within and on the edges of natural and disturbed forests (Belcher 2003, Chamberlain 1998). For the purposes of this study, tree ferns will be considered as NTFPs.

Considering the definitions and concepts described above, leaves, roots, twigs, bark, fungi, fruits and juices have been used through history by different communities living in a variety of landscapes for nutritional, medicinal, utilitarian, and artistic purposes (Chamberlain 1998, Belcher 2003). Despite the fact that the majority of scholars consider the use of NTFPs a good strategy for forest and species conservation (Gautam and Watanabe 2002, Gould, Howard and Rodriguez 1998, Jensen and Meilby 2008, Mahapatra and Mitchell 1997, Marshall and Newton 2003), others argue that the use of NTFPs can be damaging to the forest and the forest's diversity. These authors clearly state the necessity for long term research that focuses on multiple ecological levels (ranging from genes to ecosystems), assesses the mechanisms underlying impacts, and validates current models (Endress, Gorchov and Noble 2004, Martinez-Balleste *et al* 2005, Sinha and Brault 2005). Researchers and forest managers need to work with local harvesters in designing and evaluating management practices that can mitigate the negative effects of harvest (Guariguata *et al* 2008, Pulido and Caballero 2006).

Socio-economic roles of non-timber forest products

NTFPs are an important component of many rural economies, in some cases forming the basis of communities' economic systems. As a source of goods, NTFPs can be utilized within a community as a safety net if the main economic activity fails (Shackleton and Shackleton 2004). In other cases, NTFPs comprise the majority of resources used by poor households (Shackleton and Shackleton 2006). NTFPs are cited as contributing between 15 to 50% of the annual per capita income of rural households (Narendran *et al* 2001). In some developing regions of the tropics, indigenous communities obtain a large proportion of their annual per capita income from collecting NTFPs. This can be the most important activity for between 50 to 75% of the households in rural areas (Narendran *et al* 2001). In addition, non-timber forest products constitute the single largest determinant of livelihoods for scores of forest fringe communities and poor people in the tropics (Narendran *et al* 2001). In a study in India over 50 million people are thought to be directly dependent upon NTFPs for their subsistence (Shaanker *et al* 2004).

Despite the observation that income derived from the extraction of non-timber forest products is high in proportion to the time devoted to the collection, NTFP extraction is not a preferred vocation in many indigenous communities in the developing world (Hegde *et al* 1996). Price appreciation for non-timber forest products varies for different products, and overall, some communities obtain essentially minimal income for their extractive efforts (Hegde *et al* 1996). Cultural and educational background is a key determinant for the degree of dependence on NTFP extraction. The role of rural-urban dynamics underlying NTFP extraction and processing and the role that migration plays in the harvest of NTFPs for livelihood subsistence should be taken into account when assessing NTFPs-based development strategies (Stoian 2005).

To ensure the best use of forests and NTFPs, it is necessary for rural communities to share the responsibility of forest management with governmental forestry departments. However, if the state takes control of traditional usufruct rights, communities often find themselves fighting against poverty exacerbated by the governmental actions that were created to enforce conservation (Appasamy 1993). Despite the fact that NTFPs are the base of the economy and a decisive factor for poverty reduction for the communities studied, concerns about the sustainability of harvesting practices which may lead to biodiversity loss and further resource depletion are commonly raised (Pandit and Thapa 2003).

Sustainability of non timber forest product extraction

Sustainable use of non-timber forest products as a means for achieving the complementary objectives of forest conservation and income generation for rural inhabitants has drawn international attention in recent years. Sustainability analysis requires an understanding of the functioning of non-timber forest product extraction in tropical regions. This is often hindered by a lack of basic research and analysis (Mahapatra and Mitchell 1997). In this regard, the traditional harvest of non-timber forest products provides a model for integrated conservation and development programs. Some NTFPs can be promoted on international and domestic markets as sustainably extracted natural products, the sale of which provides a direct incentive for local producers to conserve their forests (Gould *et al* 1998).

An ongoing debate exists over the development potential of non-timber forest products in tropical forests, particularly about the approach that should be used to promote development (Perez and Byron 1999). Proponents of particular "solutions" for sustainable use of NTFPs, which include the market approach (improving prices for producers, adding value locally, and organizing people to achieve these aims, while increasing peoples interest in conserving forests), the technocratic approach (investment in technology for the development of NTFP harvest techniques), and the political empowerment approach (securing economic and political rights), often refer to case studies and data which tend to support their interpretation of events and relationships and do not present information that contradicts their point of view (Perez and Byron 1999). Recommendations thus frequently depend on how data are classified and interpreted; therefore, inaccurate or incomplete classification leads to defective subsequent theories, models, and recommendations (Perez and Byron 1999). For example, in Mexican forests, despite the harvest of mahogany (*Swietenia macrophylla*) having been certified as sustainable, its natural regeneration is inadequate to maintain current rates of extraction (Newton 2008). Extractive activities for NTFPs appear to be harmless or even beneficial for biodiversity in most cases (Marshall, Newton and Schreckenberg 2003), however, it seems that the sustainability –the long-term and rational use of natural resources that meets the needs of the present without compromising the ability of future generations to meet their own needs - of the activity is compromised when other activities like illegal logging or problems of land governance are taking place in the landscape managed by the NTFP-harvesting community (Marshall *et al* 2003). Furthermore, the lack of proper institutional arrangements, including the lack of a comprehensive government policy framework for sustainable use and management can lead to depletion of NTFPs (Pandit and Thapa 2003).

Implications and impacts of the use and management of non-timber forest products

NTFP management approaches are typically focused on raw material production; however, the use of NTFPs should be viewed from the perspective of ecological processes, cultural heritage, local livelihoods, economic values, and incentives for forest management (Gautam and Watanabe 2002).

NTFP harvest can affect ecological processes at many levels, from individual and population to community and ecosystem; however, tolerance to harvest varies according to life history and the part of plant that is harvested (Ticktin 2004). The effects of harvest on any species are mediated by variation in environmental conditions over space and time and by management practices (Ticktin 2004). Management practices can be carried out at different spatial scales and some are highly effective in fostering population persistence; harvest of seeds and fruits can be an example of these practices (Ticktin 2004). Researchers and forest managers need to work with local harvesters in designing and evaluating management practices that can mitigate the negative effects of harvest (Ticktin 2004, Ticktin and Nantel 2004).

The contributions that non-timber forest products can make to rural livelihoods and the fact that their use is less ecologically destructive than timber harvesting have encouraged the belief that more intensive management of forests for such products could contribute to both development and conservation objectives, and have led to initiatives to expand commercial use of NTFPs which often causes the mismanagement of the resource (Arnold and Perez 2001). This "conservation through commercialization' thesis needs to be reviewed (Arnold and Perez 2001). In practice, the selective nature of market demand and the uneven distribution of valuable resources within forests means that with NTFP harvesting the resource can become altered and degraded (Arnold and Perez 2001). The pressures that market forces can place on local control mechanisms, and the conflicting interests of those using forest resources for subsistence and income generation, can also result in poorer users becoming disadvantaged as NTFPs commercialization is intensified (Arnold and Perez 2001). In addition, the ability to select a natural population of NTFPs that presents commercial qualities and the degree of commercialization (access to the markets) are key factors for management. Poor selection ability and low degree of commercialization are associated with low daily net revenues, whereas good selection ability and high degree of commercialization are associated with high daily net revenues. In some cases, the activities of highly commercialized harvesters are less harmful to some natural populations than those of less specialized, local harvesters (Jensen and Meilby 2008).

Non-timber forest products in Mexico

In Mexico, agricultural practices often include the use of native and introduced plant species, as well as cultivated and wild plants from which NTFPs are obtained. These products are closely related to the social, economic, and ecological context. NTFPs include medicinal items, food staples, construction materials, resins, essences, natural wax, vegetable oils, seeds, leafs and mushrooms, among others. Considering that there are 25,000 species of superior plants in Mexico, only 100 are commercially exploited and less than 1000 are used regionally. Palm leafs (*Chamaedorea elegans*), *Pimenta dioica*, and white mushrooms are examples of commercialized NTFPs. The State of Michoacán has the most intensive use of NTFPs, particularly resins. Morelos and Estado de México have the highest use of *Tierra de Monte* (Secretaría de Medio Ambiente y Recursos Naturales SEMARNAT, 2003).

Land Cover Change

Although natural events cause variations in land cover, during the last decades human activities have become the main source of ecosystem transformation, (Vitousek *et al* 1997). For example, authors have estimated that almost a third to half of the original total surface of forests has been lost from the dawn of humanity to the present (Noble and Dirzo 1997; Cincotta *et al* 2000). This process has intensified during the last two centuries because population density has quadrupled, causing the loss of more forested surface than during all prior history of human kind (Cincotta *et al* 2000). This accelerated loss of forest cover implies the extermination of genes, loss of environmental services, climate change, alteration of hydrologic and biogeochemical cycles, exotic and invasive species introduction, loss of native species and loss of entire ecosystems (Velázquez *et al* 2002a).

Forest loss has been particularly notable in tropical forests. An estimate for the 1964–1973 period stated that the deforestation rate in the tropics was 21 ha/minute for a total of eleven million hectares loss. Between 1981 and 1990, land cover change reached an annual average of 15.5 million hectares. FAO estimated in 1995 that for Latin America, forest cover will be reduced by up to 53% from the original coverage (FAO 1995). These numbers on land cover and land use change are rough estimates and they often involve various methodological difficulties.

Land cover change in Mexico

Tropical forests are estimated to cover approximately 20% of Mexico's national territory. Between 1976 and 1980 the annual deforestation rate was estimated at approximately 160,000 ha/year. Different studies estimate the annual deforestation rate at between 1 and 10.4% depending on the region of focus (Velázquez *et al* 2002b). (Table 1).

Table 1: Different studies showing annual deforestation rates in Mexico

Source	**Deforested area (Ha/Year)**
SARH 1992	365,000
SARH 1994	370,000
Repetto 1988	460,000
FAO 1997	508,000
FAO 1988	615,000
Masera *et al* 1992	668,000
FAO 1995	678,000
Myers 1989	700,000
Castillo *et al* 1989	746,000
Toledo 1989	1,500,000

Different processes have been identified as responsible for land use/ land cover change. Some models indicate that population growth is responsible for the increase in area under agricultural production. Nevertheless, in the last decades agricultural land use has grown at a slower rate than world population growth in part because of greater production efficiency (Velázquez *et al* 2002a, Velázquez *et al* 2002b)..

In Mexico, 65% of anthropogenic land cover is statistically determined based on the current population density. Nevertheless, the correlation with population density was stronger in the past than it is in the present. In 1950, 75% of land use could be determined based on population demography. The shift in factors determining land use is the result of increased rural to urban migration. The remaining forest cover is located principally in indigenous territories of the country, which own approximately 60% of Mexico's forests. The states with highest poverty and largest indigenous population host a greater proportion of temperate and tropical forests, but also higher levels of forest fragmentation (Velázquez *et al* 2002b).

The conversion of lands to agricultural and pastoral land uses is one of the principal causes of deforestation in Latin America (FAO, 2001). As of 2000, the cultivated land area in Mexico was 20.2 million hectares. Nevertheless, in 2000 the National Institute of Forestry reported the presence of 32.8 million hectares of agricultural land in the same year. In other words, 12.6 million hectares available for agriculture were not in use in that moment (Velázquez *et al* 2002b).

Cattle ranching is practiced on approximately 1.1 million km^2 or 56% of the Mexican national territory. Only 16% of the territory is grassland, which indicates that at least 40% of the ranching area is located in areas with other types of natural vegetation. Only 26% of the country has land that is free of any effect from cattle ranching (SEMARNAT 2003).

The proportion of territory under urban land use is particularly small at the national scale (0.4% of the territory), but it is one of the most rapidly expanding land uses in certain regions. In total, 99,524 hectares were urbanized between 1993 and 2000. In general, urban expansion occurs in level areas of agricultural value, resulting in a loss of productive lands. While the direct impact of urban expansion is small, the indirect impacts include extensive land use associated with satisfying the food, material, recreation, and waste disposal needs of urban populations (SEMARNAT 2003).

Land use change in the tropical montane forests in Central Veracruz

Tropical montane cloud forests host unique biodiversity and provide critical environmental services at the global level, but are highly threatened, with one of the highest rates of deforestation among all tropical forests (Williams-Linera *et al* 2002). In Mexico, it is estimated that more than 50% of cloud forests have disappeared (Williams-

Linnera *et al* 2002). Historically, Veracruz ranked fourth in the nation in cloud forest area, but a large percentage of this and other types of forest have been converted to other land uses, which explain in part why more species are threatened with extinction in Veracruz than any other state. The importance of conserving cloud forests in the capital region of central Veracruz is particularly significant; the montane regions of the state represent 11.6% of the territory and are home to 26% of its total population, and between 1987 and 2000, urban areas expanded by 440% to 13,171 ha (Williams-Linera *et al*,2002).

Chapter 2: Tropical Montane Cloud Forest (TMCF)

Tropical montane cloud forests (TMCF) are a rare type of evergreen mountain forest found in tropical areas where local climatic conditions cause cloud and mist to be regularly in contact with the forest vegetation. These forests support ecosystems of distinctive floristic and structural form and contain a disproportionately large number of the world's endemic and threatened species. These forests make up no more than 2.5 percent of the world's tropical forests, and this wealth of biodiversity includes the wild relatives and sources of genetic diversity of many of our staple crops, such as beans, potatoes and coffee (Hamilton *et al* 1993).

Cloud forests are also of vital importance to local communities and people living downstream for their unique ability to capture water from the clouds, in addition to direct rainfall. Cloud forests face many of the same threats to their existence as other tropical forests, but their unique ecology and their location on mountain slopes make them particularly susceptible to habitat fragmentation and especially to climate change (Hamilton *et al* 1993).Cloud forests occur within a wide range of annual and seasonal rainfall patterns, from 500–6000 mm/year. They are found wherever clouds and mist are frequently in contact with a mountain slope. They typically form a belt of vegetation over an elevational range of about 500 m, but there is considerable variation in the altitude at which they are found. On large inland mountain systems cloud forests may typically occur between 2000 and 3500 m, whereas in coastal and insular mountains this zone may descend to 1000 m. Under exceptionally humid conditions a cloud forest zone may develop on steep, tropical islands or coastal mountains at elevations as low as 500 m (Hamilton *et al* 1993).

DEFINITION OF TROPICAL MONTANE CLOUD FOREST (TMCF)

According to the United Nations Environment Programme, cloud forests are a type of evergreen mountain forest found in tropical areas, where local conditions cause cloud and mist to be frequently in contact with the forest vegetation. It typically occurs as a relatively narrow altitudinal zone where the atmospheric environment is characterized by persistent, frequent or seasonal cloud cover at the vegetation level (Hamilton *et al* 1993) The presence of clouds and this additional input of water significantly influence the hydrology, ecology and soil properties of cloud forests (Stadtmuller 1987). Enveloping clouds or wind-driven clouds influence the atmospheric interaction through reduced solar radiation and vapor deficit, canopy wetting, and general suppression of evapotranspiration. The net precipitation (throughfall) in such forests is significantly enhanced (beyond rainfall contribution) through direct canopy interception of cloud water (horizontal precipitation or cloud stripping) and low water use by the vegetation. Soils are wet and frequently waterlogged and highly organic in the form of humus and peat (histosols) (Bubbs P. *et al* 2004).

The tropical montane cloud forest is composed of forest ecosystems of distinctive floristic and structural form. In comparison with lower latitude tropical moist forest, the stand characteristics generally include reduced tree stature and increased stem density. Canopy trees usually exhibit gnarled trunks and branches; dense compact crowns; and small, thick and hard (sclerophyllous) leaves. TMCF is also characterized by having a high proportion of biomass in epiphytes (bryophytes, lichens and filmy ferns) and a corresponding reduction in woody climbers. One of their most obvious features is an abundance of mosses, ferns, orchids and other epiphytic plants on every tree and rock surface. Biodiversity in terms of tree species of herbs, shrubs and epiphytes can be relatively high (considering the small areal extent) when compared with tree species-rich lowland rain forest. Endemism is often very high (Hamilton *et al* 1993).

A wide range of terminology is used to describe cloud forests. The term "cloud forest" or its Spanish equivalents are commonly used in association with montane forests in South and Central America, but is rarely used in Asia, Africa, Caribbean Islands or in the Oceania/Pacific region. In Asia the term “cloud forest” is best equated to the more commonly described upper montane rainforests, although the terms elfin forest and mossy forest are also used. In Africa Afromontane forest is most commonly used, as well “Upper montane forest”. The term “bosque nublado” is the most frequent denomination in Latin America to describe forest under the strong influence of clouds. “Bosque de niebla” and “selva nublada” are also used. In Mexico cloud forests are often called “Bosque mesófilo de montaña”. In the Andean region the belt of cloud forest on the mountainside is sometimes called “ceja andina”. In Peru, Bolivia and Argentina the cloud forests are often called “Yungas” (Hamilton *et al* 1993).

TROPICAL MONTANE CLOUD FOREST IN MEXICO

In Mexico, TMCF is distributed along the eastern side of the Sierra Madre Oriental in a discontinuous and narrow strip from southwestern Tamaulipas to northern Oaxaca and includes portions of San Luis Potosí, Hidalgo, Puebla and Veracruz (Figure 1). On the western side of the Sierra Madre Occidental the cloud forest’s distribution is even more scattered and can be found only in protected or inaccessible cañadas and barrancas (Rzedowski 1996). TMCF is one of the most threatened ecosystems in the country, constituting only 0.9 percent of all of forested areas (Ricker *et al* 2007).

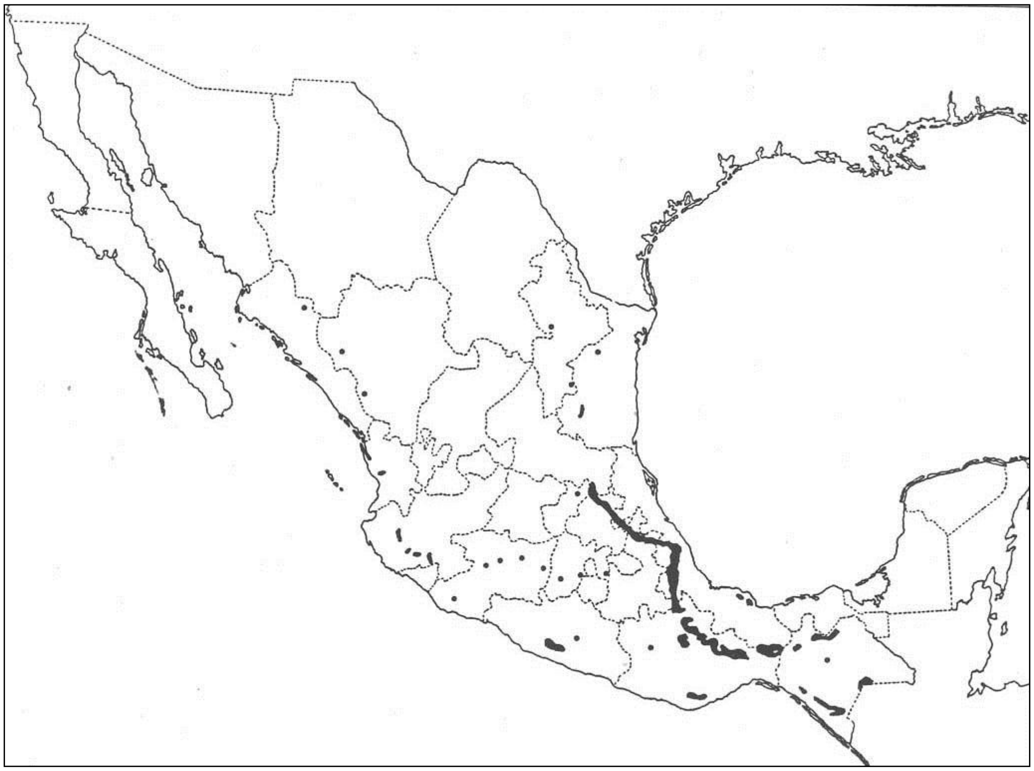

Figure 1: Original tropical montane cloud forest (TMCF) extension in Mexico (Source: Rzedowski 1996).

The Tropical Montane Cloud Forest in Veracruz, Mexico.

Because of its geographic location along the Gulf of Mexico and the Sierra Madre Oriental, the Mexican state of Veracruz has a wide variety of climates and microclimates giving rise to unique vegetation systems, including the TMCF of the Central Mountain Region. In Veracruz the TMCF is represented by forest remnants immersed in a landscape matrix of farms, coffee plots and urban and rural areas (Williams-Linera 1993). The land conversion rate of TMCF to other land uses is high in some cases only 10% of the original distribution remains (Williams-Linera 2007). However there are some remnants that remain relatively isolated and show excellent environmental conditions.

In Veracruz, TMCF can be located approximately between 1200 and 2100 m altitude on hills and mountain ranges with volcanic soils and with a great topographic and environmental heterogeneity. This type of forest thrives in a wet temperate climate with rain all year round (Figure 2) (Williams-Linera 2007). The topographic and micro-environmental variation favors different composition and structures between fragments of TMCF relatively close to each other. Several ecological and floristic studies have been conducted in order to understand this ecosystem (Williams-Linera 1997, 2002; Mehltreter *et al* 2005; Williams-Linera *et al* 2005; Flores-Palacios and García-Franco 2006; Heredia *et al* 2006; Mehltreter and García-Franco 2008).

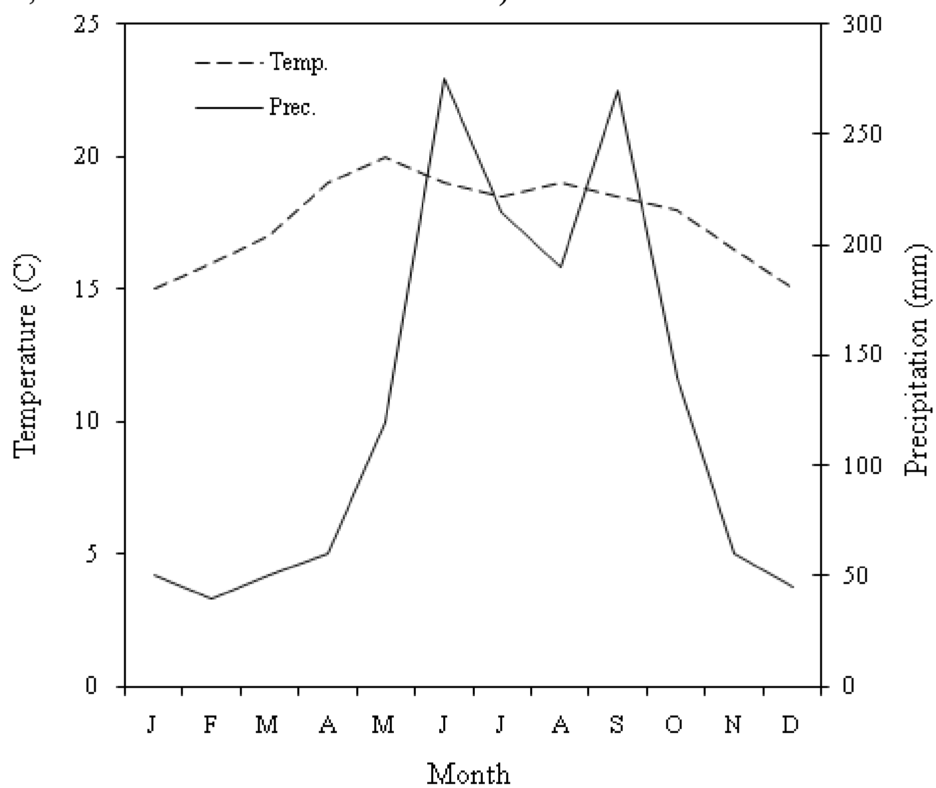

Figure 2: : Climogram for Xalapa, Veracruz, Mexico indicating mean monthly temperature and precipitation. Source: Soto and Gómez (1990).

Structure of Tropical Montane Cloud Forest (TMCF) in Veracruz

The experience of being in a cloud forest is typically one of an abundance of lush, evergreen vegetation in a cool, humid atmosphere. If clouds are present, or have recently passed through, there is a constant sound of water dripping from the leaves. The form and appearance of tropical montane cloud forests vary greatly according to how exposed they are to the prevailing winds and clouds, as well as altitude and local soil types. On lower mountain slopes, cloud forest trees are usually 15-20 m tall. At higher altitudes, where the forest is more consistently in the clouds and winds are greater, the trees are more stunted and covered in more epiphytes.

The vegetation structure of a forest is clearly manifested in the presence of the different height of the trees, shrubs and herbs in the forest understory. A stratum is a vegetation layer of height varying within certain limits. Each stratum can have a distinctive floristic composition, however, due to the constant growth and regeneration a number of trees in the lower stratum that will reach the higher strata in their maturity. A stratum of trees can form a continuous or discontinuous layer called the canopy. The canopy is made of tree tops which are approximately the same height. The trees that surpass the canopy are called "emergent" trees and they are sometimes referred to as the "giants of the forest" (Williams-Linera 2007).

The characterization of forest structure is given by the basal area, the trees' density, and the height of the canopy. Species with more basal area (more than 10% of the total basal area of the community) can be considered as the dominant species of the forest. Density is the number of trees that can be found in a given plot and is related to an area unit. The height of the canopy is the distance from the floor to the forest's canopy. Another way of assessing the structure of the forest is the clearance or openness according to the number of dead trees and the way in which they died (Williams-Linera 2007).

In the mountain ranges of central Veracruz the structure of TMCF varies depending on the location where TMCF develop. In these forests the basal area can reach up to 58 m2/ha. However, some of the forests can reach basal areas of 100 m2/ha. The average density of the trees is of 1035 trees/ha. The height of the canopy ranks from 25 to 30 meters, although trees of more than 40 meters high have been found in some areas. Trees with 70 cm in diameter exist in various areas; however, true “giants” with up to 1 meter in diameter can be found only in some remote fragments of TMCF (Williams-Linera 2007).

Chapter 3: Tree Ferns

TAXONOMY

Tree ferns are vascular plants which are classified taxonomically in the Regnum Plantae, Division Pteridophyta (Table 2). The following is a description of the two main families of tree ferns and the genera of tree ferns found during this research.

Cyatheaceae

Cyatheaceae Kaulfuss 1827. Alsophilaceae C.B. Presl 1847.

The Cyatheaceae family is integrated by terrestrial ferns (with one species, *Cyathea gracilis*, sometimes epiphytic) with tree-like trunks. Few species may have a creeping rhizome, and there are creeping variants in normally arborescent species. The family includes the tallest tree ferns with trunks exceeding 20 m (Large and Braggins, 2009). All Cyatheaceae have scales instead of hairs. Fronds of this family are among the largest leaves in the plant kingdom. In some species the fronds can reach 3-4 m in length and final crown width of 6 m. Sori occur away from the margins of the pinnules and take the form of elongate or rounded receptacles. The sorus is often enclosed by a thin indusium. Spores are rounded-triangular (trilete) (Large and Braggins, 2009). Traditionally, the Cyatheaceae has been regarded as the largest group of living tree ferns and fossils attributed to this family appear for the first time in late Jurassic to early Cretaceous sediments. Modern genera of the family may have an origin as late as the Tertiary (Large and Braggins, 2009).

Dicksoniaceae

Dicksoniaceae Bower 1908, as Dicksoniaceae. Thyrsopteridaceae C. B. Presl 1847 as order Thyrsopteridaceae; Culcitaceae Pichi-Sermolli 1970. Lophosoriaceae Pichu-Sermolli 1970, Cystodiaceae J. R. croft 1986.

This family comprises mostly terrestrial ferns but includes some epiphytes (some species of *Cibotium*, and *Culcita connifolia*, which may be terrestrial or epiphytic), generally but not always with rhizomes forming tree-like trunks. All Dicksoniaceae have long, tapering hairs composed of cells arranged end to end, rather than scales (characteristic of Cyatheaceae). Fronds may be 1-3 m in length. Sori occur toward the margins of the pinnules and take the form of elongate or rounded receptacles. The sorus is enclosed by a thin indusium and a small reflexed lobe of the frond lamina. Spores are rounded-triangular (trilete) (Large and Braggins 2009).The Dicksoniaceae have a long fossil record, extending into the early Jurassic or earlier. The history of the family compresses early diversity and periods of extinction (Large and Braggins 2009).

Alsophila

Alsophila R. Br., Prodr. 158. 181o. Type: *Alsophila australis* R. Br. (additional synonymy in R. Tryon, 3970). Nephelea R. M. Tryon, Contr. Gray Herb. zoo: 37. 1970. Type: *Nephelea polystichoides* (Christ) R. M. Tryon *Cyathea polystichoides* Christ].

Terrestrial; stems decumbent to erect, to 15 m, with or without spines; fronds to 4.2 m, short-sessile to long-stipitate; stipes brown to black, smooth or spiny; stipe base scales concolorous or bicolorous, marginate, with an apical seta or with apical and lateral setae, also with squamules; blades pinnate-pinnatifid to quadripinnate; rachises with hairs, scales and squamules; veins free, mostly simple; indusia globose (sphaeropteroid) or absent; sporangia x6-spored, 64-spored in *A. salvinii*; x=69 (Palacios-Ríos, 1992b).Alsophila is a genus of ca. 235 species 'in the New and Old World tropics, three in Mexico. Recent treatments have submerged Nephelea under Alsophila. The genus is distinct from other tree ferns by its frond scales bearing black acicular setae (Palacios-Ríos, 1992b).

Cyathea

Cyathea Sm., Mem. Acad. Roy. Sci. (Turin) 5: 456.5793. Type: *Cyathea arborea* (L.) Sm. Polypodium arboreum L.]. Hemitelia R. Br., Prodr. 158. 181o. Type: *Hemitelia multiflora* (Sm.) Spreng. = *Cyathea multiflora* Sm. Trichipteris C. Presl in J. Presl & C. Presl, Delic. Prag. 1: 172.1822. Type: *Trichipteris excelsa* C. Presl = *T corcovadensis* (Raddi) Copel. = *Cyathea corcovadensis* (Raddi) Domin. Sometimes treated as Trichopteris (Palacios-Ríos, 1992b).

Terrestrial; stems erect, usually forming massive trunks to 20 m tall, to 10 cm diameter. Without the occasional mantle of wiry adventitious roots, scaly at apices; fronds large, to 4 m long; stipes stout, scaly, scales conform or marginate, concolorous to bicolorous, without dark apical setae, cells of the margins lightly to strongly different from those of the center in size, shape, and orientation; blades 2-3+-pinnate, chartaceous to coriaceous; axes with long, curved, acicular hairs adaxially, often with bullate scales abaxially, the rachises and costae rarely with spines; veins free, simple or forked; sori round, medial, with raised receptacles, indusia arising from beneath the sori and either completely enclosing them or forming cups or flat unequal-sided saucers, or absent; sporangia with slightly oblique annuli; spores tetrahedral-globose, 64 per sporangium; x=69. Cyathea is a genus of about 115 species, 8 in Mexico. The scaly tree ferns have been treated as a single genus and as six genera (Palacios-Ríos, 1992b).

BIODIVERSITY AND GLOBAL DISTRIBUTION

Tree ferns are found in tropical lowland to submontane environments as well as subtropical and Southern Hemisphere temperate forests. The majority form a component of humid forests in the Caribbean, Central and South America, Asia, Africa, New Guinea, Oceania, Australia and New Zealand. Several reach cool latitudes in southern South America, Tasmania and Southern New Zealand. *Cyathea smithii* is known from some of the sub-Antarctic Auckland Islands, south of New Zealand and is the most southerly tree fern in the world. In tropical areas, tree ferns may reach high montane zones, as high as 4200 m in elevation in the Andes. Members of the family Cyatheaceae are the most widespread tree ferns. Many species show a high degree of local endemisms. Centers of diversity include the Greater Antilles, Meso- and Central America, the Andes, Madagascar, Malaysia, Indonesia, Philippines, and New Guinea (Large and Braggins, 2009).

The family Dicksoniaceae is Pantropical with a high degree of diversity in Indonesia and New Guinea. Some species have a relictual distribution, with different endemic species occurring in places as isolated as St. Helena in the Atlantic Ocean and Juan Fernández Islands off the coast of Chile (Large and Braggins, 2009).

DISTRIBUTION IN MEXICO

In Mexico, tree fern species are distributed in different vegetation types such as Tropical Montane Cloud Forest, Rain Forest, Alder Forest, Oak Forest, Liquidambar Forest, Tropical Evergreen Forest, Tropical Deciduous Forest, and ecotones conformed by these types of vegetation. Tree ferns can be found in *cañandas* and *barrancas*, alongside rivers and rivers, and in shaded coffee plantations. Some of the Mexican states with tree ferns are San Luis Potosí, Guerrero, Querétaro, Jalisco, Hidalgo, Estado de México, Puebla, Veracruz, Oaxaca, and Chiapas (Palacios-Ríos and Mehltreter 1999).

Table 2: Taxonomic classification of the tree ferns registered for the state of Veracruz

Division	**Pteridophyta**		
Class	Filicopsidae		
Order	Filicales		
Family	Cyatheaceae Kaulf. (Palacios-Ríos, 1992b)	Dicksoniaceae Bower (Palacios-Ríos, 1992a)	Lophosoriaceae Pic. Serm. (Palacios-Ríos, 1992b; Riba, 1993a)
Genus	Alsophila R. Br.	Cibotium Kaulf.	Lophosoria Presl
	Cnemidaria Presl	Culcita Presl	
	Cyathea J.E. Smith	Dicksonia L' Hèr.	
	Sphaeropteris Bernh.		
Species	*Alsophila firma* (Baker) D.S. Conant	*Cibotium regale* Verschaff. & Lem.	*Lophosoria quadripinnata* (Gmel.) C.Chr.
	A. salvini Hook.	*C. schiedei* Schltdl. & Cham.	
	A. tryoniana (Gastony) Conant	*Culcita coniifolia* (Hook) Maxon	
	Cnemidaria apiculata (Hook & Bak.) Stolze	*Dicksonia sellowiana* Hook.	
	C. decurrens (Liebm.) Tryon		
	Cyathea bicrenata Liebm. [=*Trichipteris bicrenata* (Liebm.) Tryon]		
	C. divergens Kunze var. tuerckheimii		
	C. fulva (Martens & Gal.) Fée		
	Sphaeropteris horrida (Liebm.) Tryon		

In Veracruz, the municipalities with the most tree fern species richness and abundance are Acajete, Altotonga, Atzalan, Banderilla, Catemaco, Chiconquiaco, Chocamán, Coatepec, Córdoba, Coscomatepec, Fortín de las Flores, Huayacocotla, Huatusco, Jalacingo, Misantla, Orizaba, San Andrés Tuxtla, Santiago Tuxtla, Soteapan, Tepetzintla, Tlapacoyan, Totutla, Xalapa, Xico, Yecuatla, Zongolica and Zontecomatlán. The majority of these municipalities are located in Central Veracruz (Palacios-Ríos and Mehltreter 1999).

USE OF TREE FERNS IN CENTRAL VERACRUZ

The main use of tree ferns in Central Veracruz is the extraction of *maquique*. "*Maquique*" is the material of adventitous roots which surrounds and protects the trunk of some tree ferns. This material is considered a good substrate in the cultivation of orchids, bromeliads, ferns, and other epiphytic plants under the assumption of having good moisture retention, good drainage, and slow decay. Diverse handcrafts like sculptures, plant pots, and souvenirs are made with *maquique*, often with material obtained from tree ferns more than 60 and up to 100 years in age. Problematically, the majority of tree ferns exhibit slow growth rates (Palacios-Ríos and Mehltreter 1999). The formation of sufficient *maquique* for commercial purposes occurs only in plants that are at least 50 years old. Prior to 1975, Mexican tree fern species were exported to the United States of America and to Europe. Today, *maquique* is being sold domestically in some private ornate plant nurseries, local marketplaces, and sometimes on streets in towns and cities throughout the state of Veracruz. Cyatheaceae and Dicksoniaceae are the families most affected by *maquique* extraction. Harvesting occurs entirely from natural populations of tree ferns. Until present, there are no cultivation or reforestation projects involving tree ferns in Veracruz. Other uses of tree ferns include as construction materials and for traditional medicinal remedies (Palacios-Ríos and Mehltreter 1999).

In consequence of their use and commerce as well as deforestation and habitat destruction due to anthropogenic land cover change, as well as natural environmental change from hurricanes, wild fires and flooding events, most of the Mexican tree fern species are endangered under the Mexican and International law, making the use, extraction, and commercialization of parts and whole tree fern plants illegal (Palacios-Ríos and Mehltreter 1999).

Chapter 4: Study area

LOCATION

The study area is located in Central Veracruz in the Cofre de Perote region between the coordinates 19° 90’-19° 25’ N and 96° 30’- 97° 20’ W. This region encompasses three different terrestrial systems or landscapes: Tropical Landscape, Transitional or Intermediate Landscape and High Mountains Landscape. The region ranges from sea level to 4250 meters in elevation. This research was conducted in the localities of El Zapotal in the municipality of Acajete and El Riscal in the municipality of Coatepec (Figure 3), both located in the Intermediate Landscape. This landscape ranges from 1000 to 2600 meters in elevation characterized by the presence of sierras and cañadas. The average annual temperature is between 12.26^{o} C and 22.3^{o} C and the total annual precipitation is between 1200 and 2500 mm. Tropical Montane Cloud Forest, Oak Forest, Pine-Oak and Oak-Pine Forests are the most important vegetation types in the area. Land use is mainly dedicated to maize cultivation, coffee plantations, and dairy farms (Arellano-Gamez, 2006).

VEGETATION

The study sites are characterized by TMCF vegetation. The floristic composition of TMCF in Veracruz can be grouped by strata. Generally speaking, the arboreal stratum consists of tree and tree fern species. The shrub stratum includes species of immature trees, species of small trees and bushes. The herbaceous stratum hosts ferns and allies, herbaceous vascular and non-vascular plants, mosses and liverwort plants. However, some strata classifications include the epiphytic stratum and include lichens and epiphytic plants. Whereas tree species in the arboreal stratum are dominated by Holarctic taxa such as *Carpinus*, *Liquidambar*, and *Quercus*, Neotropical taxa occupy the shrub stratum and dominate the epiphyte community (Webster 1995).

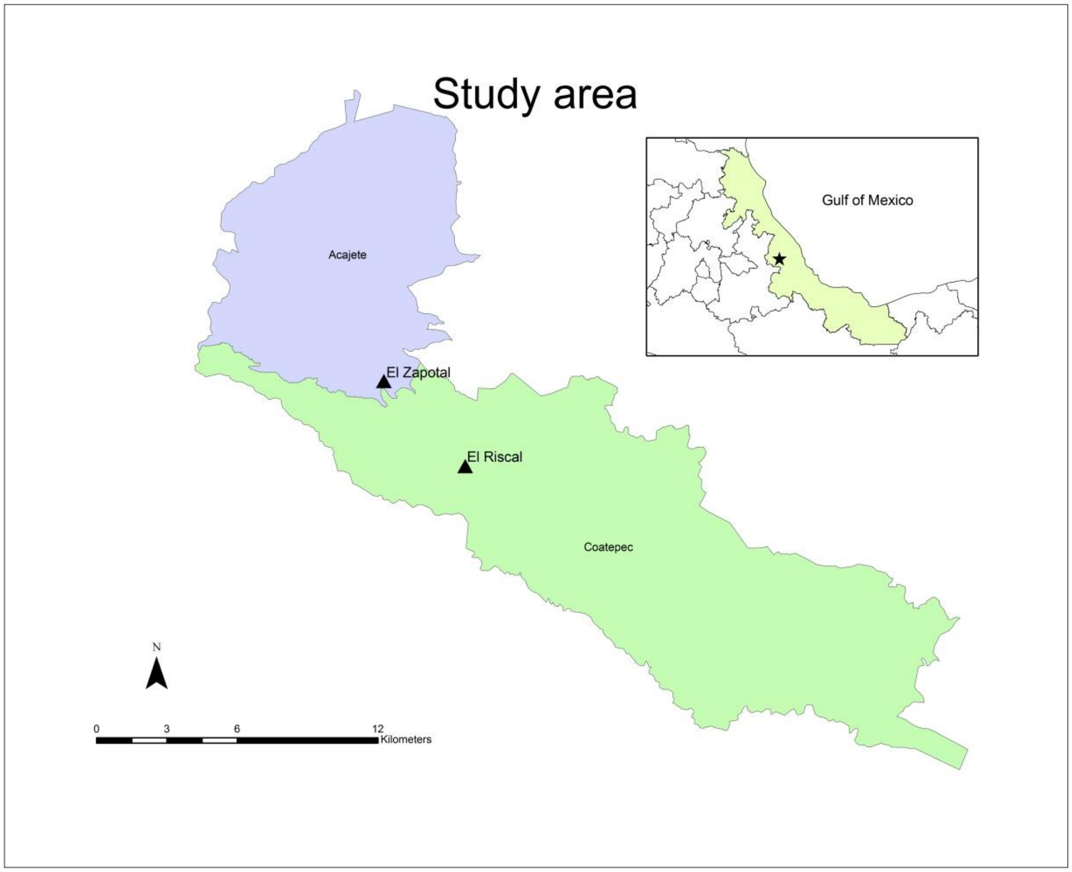

Figure 3: Localities of El Zapotal and El Riscal

The most important or dominant species in the arboreal stratum are *Carpinus caroliniana*, species of the genera *Dendropanax* and *Oreopanax*, *Cedrella odorata*, *Alnus jorullensis, Arbutus xalapensis, Fagus grandifolia, Ostrya virginiana, Liquidambar styraciflua, Platanus mexicana, Cornus sp., Prunus sp., Rhamnus sp., Clethra mexicana, Cleyera sp., Heliocarpus sp., Magnolia sp., Perroetia sp., Persea sp., Salix sp., Saurauia sp., Styrax sp., Turpinia sp., Eugenia sp., Ilex sp., Meliosma alba, Parathesis melanosticta, Hedyosmum mexicanum, Miconia chysoneura, Alchornea latifolia, Mausania deppeana, Myrsine coriacea, Cinnamomun sp., Trichilia sp., Miconia glaberrima Miconia oligotricha, Psychotria galleotiana; Sambucus nigra subsp.*

canadensis, Sideroxylon capiri, Symplocos coccinea,; Myrsine coriacea, Ocotea psychotrioides, Vaccinium leucanthum, Quercus glabra, Q. alba, Q. germanica Q. acutifolia, Q. xalapensis Q. insignis, Q. leiophylla and other several species of oaks. The tree ferns are represented by *Cyathea fulva, C. bicrenata, C. arborea, C. mexicana, Alsophyla firma and Dicksonia sellowiana*. Occasionally species of *Pinus patula, P. cembroides, P. oaxacana, P. rudis*, *P. ayacahuite* and *P. chiapensis* along with *Cupressus benthamii* can be observed in the TMCF areas (Franco *et al* 2008, Williams-Linera 2002).

The species in the shrub stratum include all the species listed above when immature plus the following: *Hoffmannia excelsa, Psychotria sp., Lycianthes geminifl ora, Deppea grandiflora, Smilax jalapensis, Smilax mollis, Fuchsia microphylla, Solanum nudum , S. pubigerum; S. rovirosanum, Urera caracasana, Witheringia solanacea; Bartlettina xalapanan, Cestrum elegans, Prunus samydoides, Cyclanthera langaei; Hanburia mexicana, Serjania sp., Vitis bourgaeana; Marcgravia stonei, Macleania sp.,* and *Passiflora sexflora* (Franco *et al* 2008, Williams-Linera 2002).

The herbaceous stratum is often the most diverse, with species like *Roldana lanicaulis, Nopalxochia phyllanthoides, Peperomia aff. quadrifolia , Anthurium scandens, Ichnanthus pallens, Megalastrum pulverulentum, Peperomia tetrophylla, Sticherus palmates, Chamaedorea sp*. Species of the families Campanulaceae, Compositae, Asteraceae, Verbenaceae and Commelinaceae are among the most common. In the same stratum the ferns and allies can account for up to 20 percent of all species. The most representative are *Selaginella martensii, Blechnum glandulosum, Selaginella galeottii, Pteris orizabae, Ctenitis hemsleyana, Lophosoria quadripinnata, Elaphoglossum seminudum, Asplenium miradorense, Elaphoglossum muelleri, Arachniodes denticulate, Sticherus palmatus, Polystichum distans, Phanerophlebia* *nobilis var. nobilis, Selaginella pulcherrima, Adiantum farinosa, Adiantum capillus-veneris, Polypodium plebeium, P. longepinnulatum, Pecluma dispersa, Pleopeltis crassinervata, Hymenophyllum tunbrigense, Polypodium, Phlebodium pseudoaureum, Vittaria graminifolia, Polypodium rhodopleuron, P. loriceum, Hymenophyllum polyanthus, Pleopeltis fallax, Trichomanes reptans, Polypodium lepidotrichum, Elaphoglossum vestitum, Adiantopsis radiate, Asplenium abscissum, Blechnum schiedeanum, B. stoloniferum, Botrychium decompositum, B. virginianum, Ctenitis equestris, Dennstaedtia distenta, Diplazium franconis, D. plantaginifolium, Elaphoglossum erinaceum, Hypolepis nigrescens, Lycopodium clavatum, L. thyoides, Mildella intramarginalis var. serratifolia, Polystichum ordinatum, Pteris quadriaurita, Thelypteris scalaris, Asplenium cuspidatum, Hymenophyllum hirsutum, Melpomene leptostoma, Pecluma consimilis, Polypodium eatonii, P. fraternum, P. puberulum,* and *Trichomanes pyxidiferum* (Franco *et al* 2008, Williams-Linera, Palacios-Ríos and Hernandez-Gomez 2005). The most common families in the epiphytic stratum are Orchidaceae, Bromeliaceae, and epiphytic ferns.

Chapter 5: Research Approaches

Research Questions

In the tree fern literature, it is commonly argued that slow growth and the lack of regeneration of tree fern caudexes make tree fern populations prone to disappear from an area when individuals are subjected to *maquique* harvesting (Palacios-Ríos and Mehltreter 1999). Regeneration after *maquique* extraction is not thought to occur and harvesting of the entire tree fern in the process of *maquique* extraction is thought to endanger populations by inducing the specimen's death (Palacios-Ríos and Mehltreter 1999). Furthermore, it is assumed that the harvesting of *maquique* is indiscriminate regarding tree fern species (Palacios-Ríos and Mehltreter 1999).

During an exploratory excursion in the study area, tree ferns with signs of *maquique* harvesting (machete cuts, "C" cuts) were observed, as well as regenerations growing from previously cut areas. Furthermore, it was observed that both *maquique* harvest cuts and the presence of regenerations were located almost entirely in a single species.

This research focuses on documenting and explaining these findings regarding *maquique* harvest and regeneration patterns. It is first hypothesized *maquique* harvest does not necessarily cause tree ferns to die, but that regeneration occurs. This study further hypothesizes that *maquique* harvest is directed at specific species, and that these species also tend to regenerate the most. This study posits that regenerated individuals are more likely to be located adjacent to points of forest access, such as trails or rivers, due to the rugged landscape and clandestine nature of harvest conditions, which may lead to preferential targeting of “easy in-and-out” areas. Lastly, despite tree ferns’ ability to regenrate, *maquique* harvesting is likely to influence the demographic characteristics of tree fern populations, such as mean size of individuals and plantlet abundance.

METHODOLOGY

Fieldwork

Two sites with populations of tree fern species with a history of *maquique* extraction were selected for this research. In the municipality of Acajete, a 2-hectare ejido parcel with extensive past *maquique* harvest history was selected for study in the locality of El Zapotal (Figure 4). The last known date of *maquique* extraction at this site was in 2008, 2 years before this study. At that time, the disturbed TMCF fragment at the site was cleared of trees to establish pine (*Pinus patula*) plantations. Tree ferns were protected during the reforestation (Figure 5). The second site is located in the municipality of Coatepec on a 10 hectare private preserve in the locality of El Riscal (Figure 6). Much of this site was in pasture for dairy production until 20 years ago, with some patches of original TMCF vegetation set aside. TMCF patches in the preserve are well conserved and have been protected from tree fern harvest for the past 10 years, but illegal extraction occurs on an occasional basis.

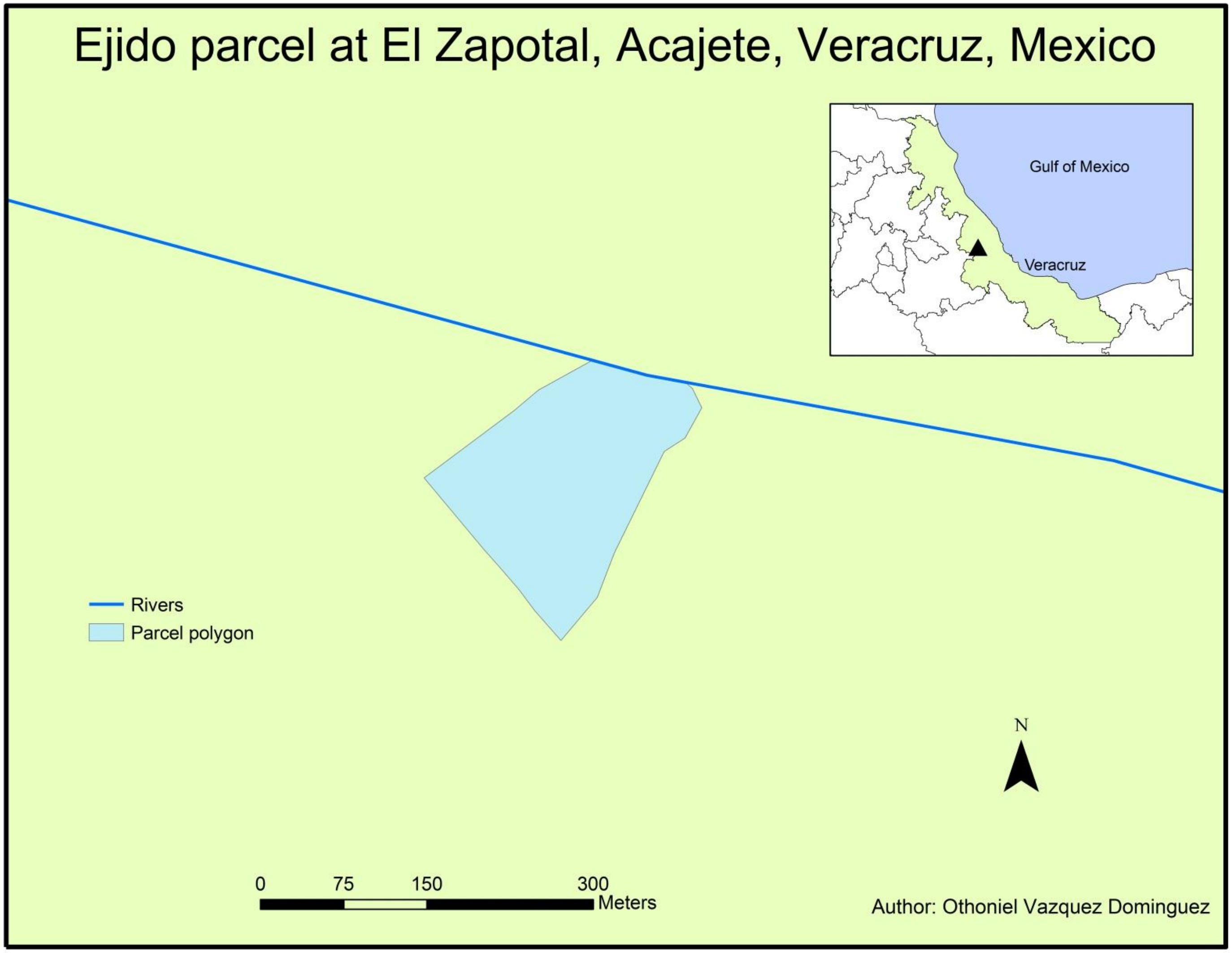

Figure 4: Polygon of the Ejido parcel at El Zapotal

Figure 5: Pine plantation with tree ferns at El Zapotal

A census of tree ferns was conducted in both sites following a modified census technique used for this purpose on Barro Colorado Island (Condit, R. 1998). Dead or alive, every individual of every tree fern species present was counted. Coordinates for each individual were recorded using a GPS unit (Garmin GPSMap 60cx). Each tree fern was measured in diameter using a diametric measuring tape at breast height (1.3 m) above the ground. In the case of smaller individuals (with trunks lower than 1.3 m) and plantlets, the diameter was taken at the base of the crown below the area where the bases of the fronds are attached to the caudex (trunk). Height (from the base of the fern to the top of the crown) was calculated based on clinometer measurements. When the top of the crowns were at arm’s length reach, a simple measuring tape was used.

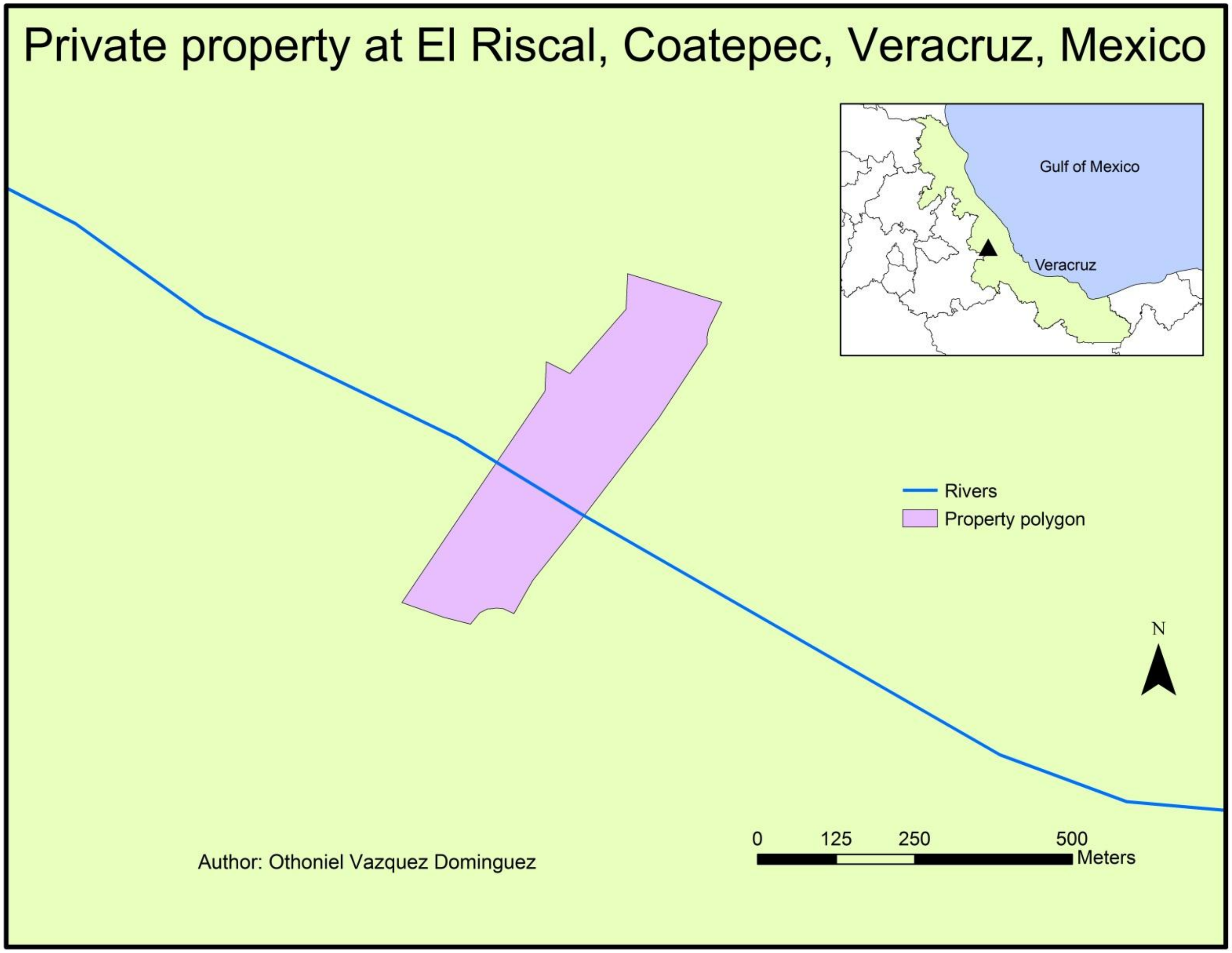

Figure 6: Polygon of the Private Property at El Riscal

The number of regenerated tree fern caudexes and the number of regenerations were registered. During this research it was assumed that "through and through" linear scars, resprouted caudexes and resprouts from a "C cut" were regenerations. Fronds with reproductive structures and other parts of the plant such as sori and scales necessary for species identification purposes were collected. Those materials were pressed, dried and treated against insects and fungi in order to be taken into the herbarium XAL at the Instituto de Ecologia A.C. (INECOL), where the samples were identified to the taxonomic level of specie. The samples are waiting to be included in the Pteridophyta Collection in the section of tree ferns (Cyahteaceae) of the XAL Herbarium.

Data analysis

All the tree fern individuals were mapped (Figures 7 and 8) using the ESRI Arc GIS Desktop 9.3 in order to perform calculations of distances from each individual tree fern to the closest trails, roads, and rivers (considered points of harvest access) present in both sites using the Near Distance Tool. The trails were digitized from GPS track points. The distances obtained were utilized along the data on heights, diameters and regenerations in order to perform statistical analysis of the relationships between variables.

Statistical data analyses were carried out in SPSS 16.0. The Pearson chi-square test was used to test for differences between observed and expected frequencies for two or more samples of categorical data, such as locality and presence of regenerations; samples with an expected count of less than 5 were excluded from chi-square analyses. The t-test was used to test for differences between two quantitative continuous variables with large sample sizes, such as *maquique* presence and tree fern diameter. Simple linear regressions were performed to test for relationships between two quantitative continuous variables, such as distance to trail/river and diameter. Non-normal variables were transformed prior to regression analysis using square root or log functions. All tests were conducted with a significance level of 0.05.

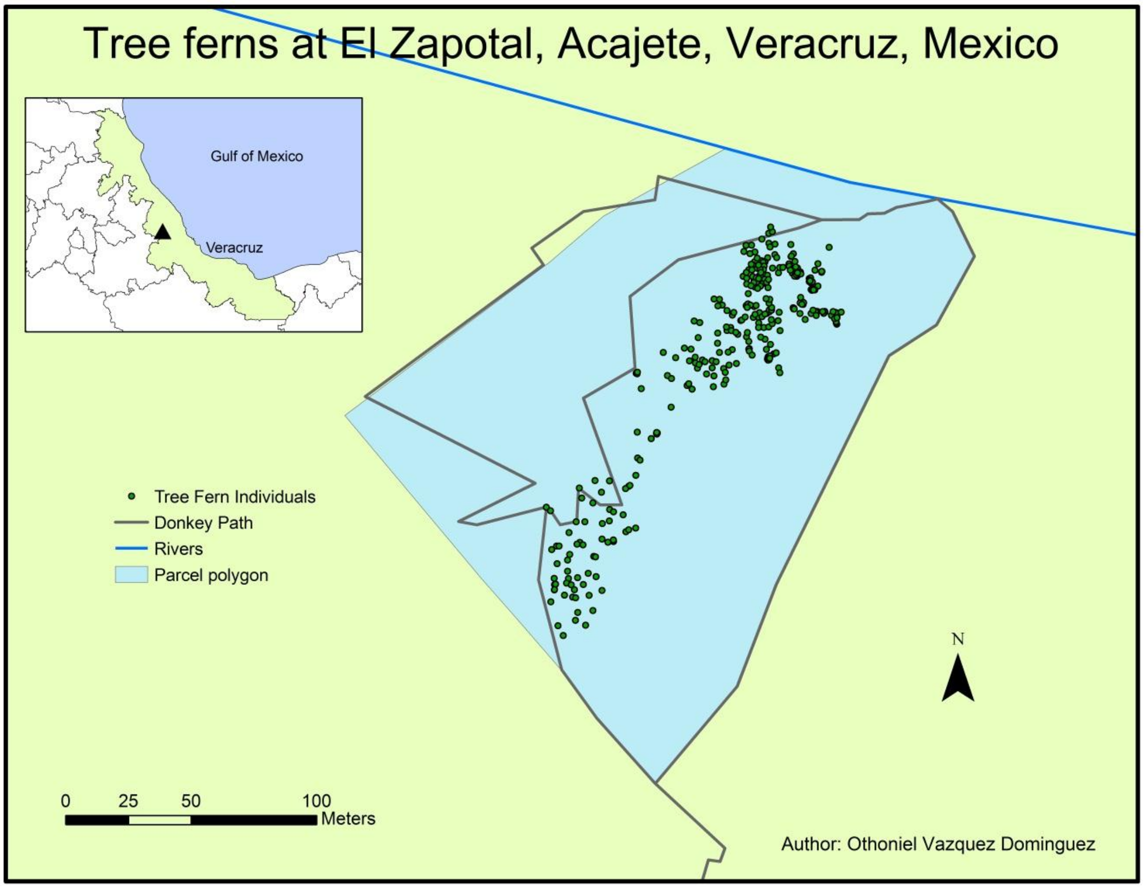

Figure 7: Georeferenced tree ferns at El Zapotal

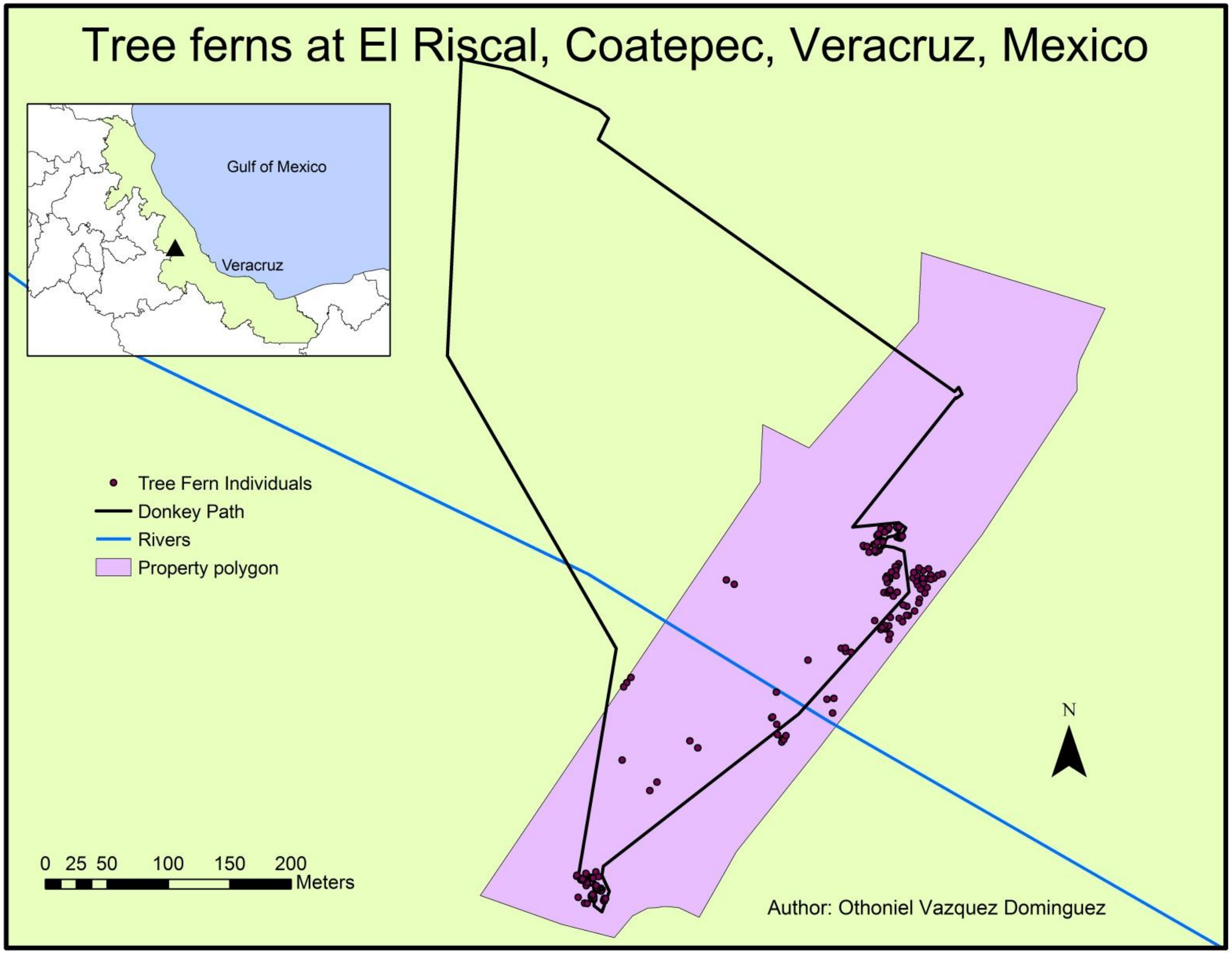

Figure 8: Georreferenced tree ferns at El Riscal

Chapter 6: Results and Discussion

IN SITU OBSERVATIONS

The site at El Zapotal was a 2 ha ejido parcel that had been cleared of trees and reforested with pine trees (*Pinus patula*) (Figure 9). The landowner preserved every tree fern on his property because he considers them as resources and of an aesthetic value. This pattern of deforestation-reforestation is commonly observed throughout El Zapotal's vicinity (Figure 10). It is worth mentioning that tree ferns were growing from regenerated caudexes in other parcels nearby which are dedicated to agriculture and for pasture (Figures 11). Some were growing in areas of the town (Figure 12). The site at El Riscal was a 10 ha private property/natural preserve which had been protected against forest products extraction. It had areas with patches of original TMCF, secondary growth forest and pastures. The landowner said that some people were caught in the act of *maquique* harvesting on his property and were turned over to the local authorities, but harvesting in general is infrequent on his property.

In both sites, some tree fern individuals exhibited signs of previous harvesting for *maquique*, some of which had regenerations present. Evidence for *maquique* harvesting includes the presence of individuals showing "through and through" linear scars left by machete cuts that completely felled the tree fern caudex (Figures 13 and 14), unfinished *maquique* gathering and plank making (Figure 15), felled tree fern caudexes (some showing signs of regeneration) (Figure 16) and tree fern caudexes with a "C" cut (Figure 17).

Figure 9: *Pinus patula* at El Zapotal

Figure 10: Deforestation pattern with tree ferns at El Zapotal

Figure 11: Bean field with resprouting tree ferns at El Zapotal

The “C” cut is a very distinctive way of extracting *maquique* in which an incision is made resembling a letter C at the base of a tree fern, which removes a portion of the caudex but does not completely sever it. This cut avoids doing considerable damage to the fern’s vascular system. Other forms of regeneration observed at the sites were the formation of multiple branches (Figure 18) and caulescent bulbs in individuals of *Alsophila firma* (Figure 19).

A total of 538 tree fern individuals were registered, 337 at El Zapotal and 201 at El Riscal. Four species were identified, *Alsophila firma* (Figure 20), *A. tryoniana* (Figure 21), *Cyathea bicrenata* (Figure 22) and *C. fulva* (Figure 23). Two other species were identified only at genus level (Table 3). From those 538 individuals a total of 124 were plantlets (Figure 24) (Table 4).

Table 3: Number of tree fern individuals by species and by site

	El Zapotal		**El Riscal**		
Species	**Dead**	**Alive**	**Dead**	**Alive**	**Total**
Alsophila firma	60	190	9	176	435
Alsophila tryoniana	5	21		8	34
Alsophila sp	4	20			24
Cyathea bicrenata	1	17		8	26
Cyathea fulva	1	16			17
Cyathea sp		2			2
Total	**71**	**266**	**9**	**192**	**538**

Table 4: Number of plantlets by species per site

Site	***Alsophila firma***	***Alsophila tryoniana***	***Alsophila sp***	***Cyathea bicrenata***	***Cyathea fulva***	**Grand Total**
El Zapotal	51	4	8	1	2	66
El Riscal	53	1		4		58
Total	**104**	**5**	**8**	**5**	**2**	**124**

Figure 12: Tree fern growing in the town of El Zapotal

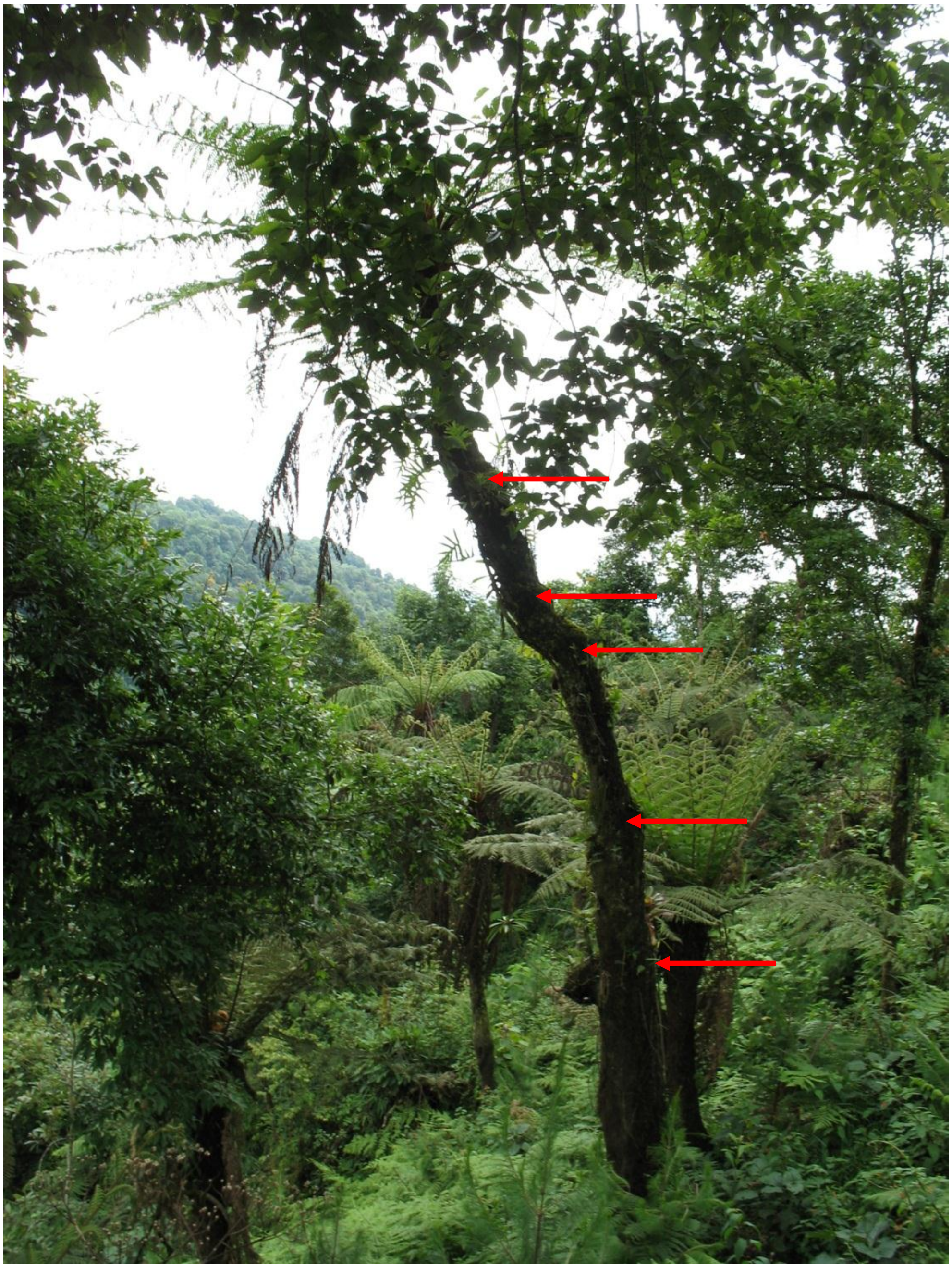

Figure 13: Tree fern showing scars from previous harvests (each bend-indicated by an arrow- is a “through and through” machete cut that resprouted)

Figure 14: Tree fern resprouting from a severed caudex at the dashed line

Figure 15: Unfinished *maquique* gathering and plank making

Figure 16: Resprouted felled tree fern

Figure 17: “C” cut

Figure 18: Multiple branch regeneration

Figure 19: Caulescences

Figure 20: *Alsophila firma*

Figure 21: *Alsophila tryoniana*

Figure 22: *Cyathea bicrenata*

Figure 23 *Cyathea fulva*

Figure 24: Plantlet of *Alsophila firma*

TREE FERN DEMOGRAPHIC PROPERTIES

The following analyses used combined data from both localities. Significant differences were found in the proportion of dead tree ferns between the two study localities, El Riscal and El Zapotal, with a greater than expected number of dead present at El Zapotal (Pearson chi-square = 23.791, P = < 0.001) (Table 5). This result confirms that tree fern harvesting was more intensive in the past at El Zapotal than at El Riscal and allows comparison of the sites based on conservation status.

Table 5: Observed and expected number of living and dead tree ferns according to locality. Expected values in parentheses. $P = < 0.001$

Species	**Alive**	**Dead**
El Riscal	200 (218.6)	71 (52.4)
El Zapotal	134 (115.4)	9 (27.6)

There were no significant differences in the proportion of tree fern plantlets between the two study localities, El Riscal and El Zapotal (Pearson chi-square = 0.200) (Table 6). This indicates that despite higher mortality from harvesting at El Zapotal, reproduction has not been significantly impacted.

Table 6: Observed and expected number of plantlet and mature tree ferns according to locality. Expected values in parentheses. $P > 0.05$

Species	**Plantlet**	**Mature**
El Riscal	58 (52)	134 (140)
El Zapotal	66 (72)	200 (194)

There was no significant difference in tree fern height between locations ($t = 0.480$, 331 df) (Figure 25). In contrast, there was a significant difference in tree fern diameter between locations ($t = 4.631$, 331 df, $P < 0.001$) (Figure 26). Tree ferns likely reach a growth plateau in terms of height, but continue developing in diameter. This lateral growth includes the production of *maquique* in certain species. It is possible that certain site-specific ecological conditions in El Zapotal, such as slope or soils, have favored the development of larger tree ferns than in El Riscal, but such factors were not examined systematically by this study.

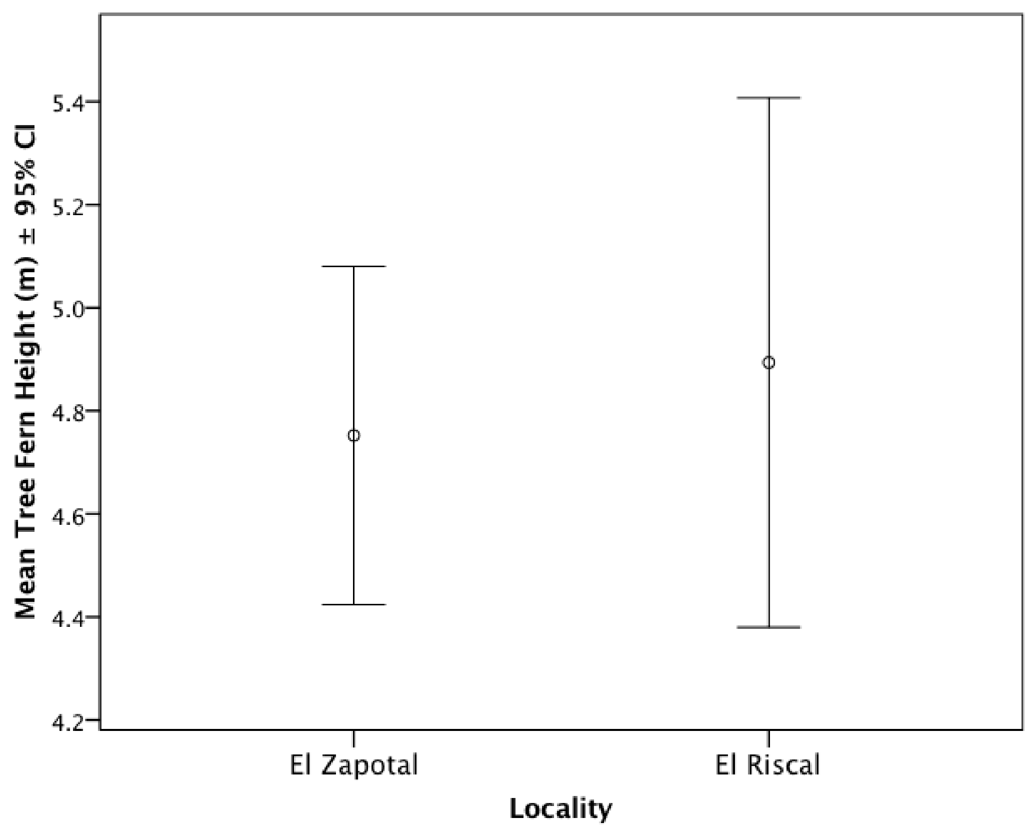

Figure 25: Mean tree fern height by locality

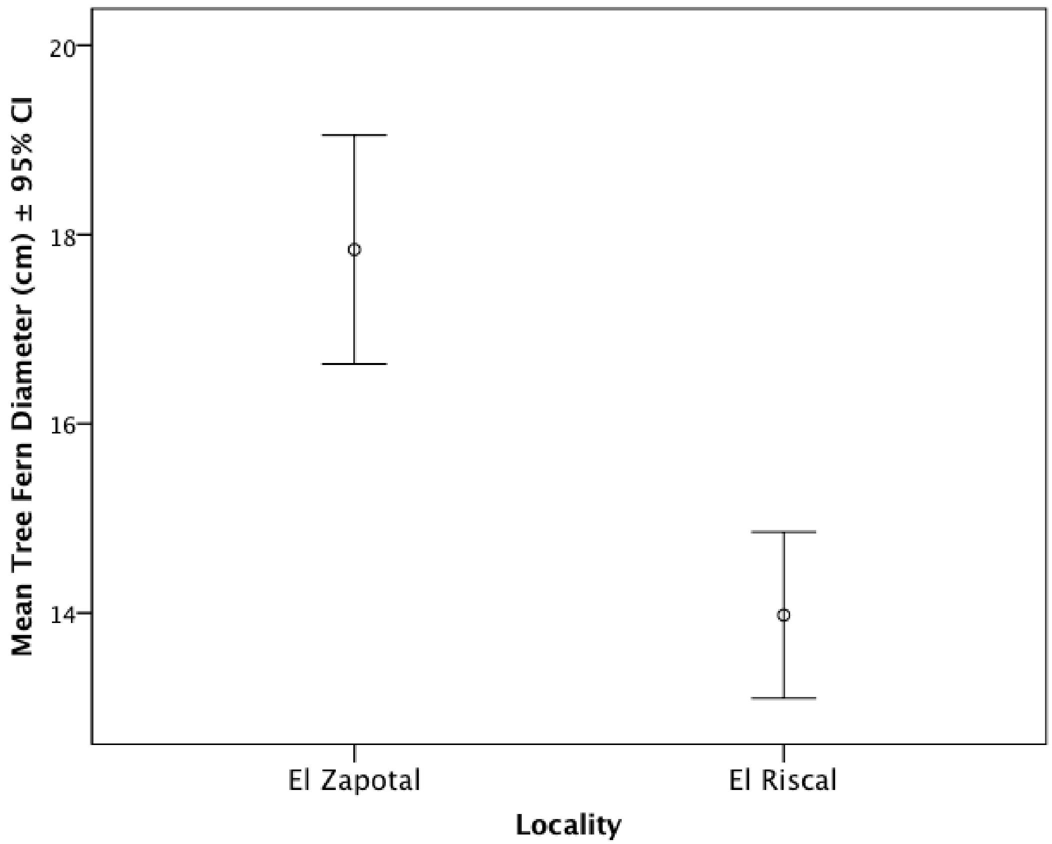

Figure 26: Mean tree fern diameter by locality

RELATIONSHIPS BETWEEN REGENERATIONS AND TREE FERN PROPERTIES

The majority of tree ferns in the censuses at both El Zapotal and El Riscal were lacking regenerations (Figure 27). Of those with regenerations, only a small number had multiple regenerations present, indicating repeated *maquique* harvesting had occurred. The small number of tree ferns with more than one regeneration present made regression analysis using the regenerations variable impossible.

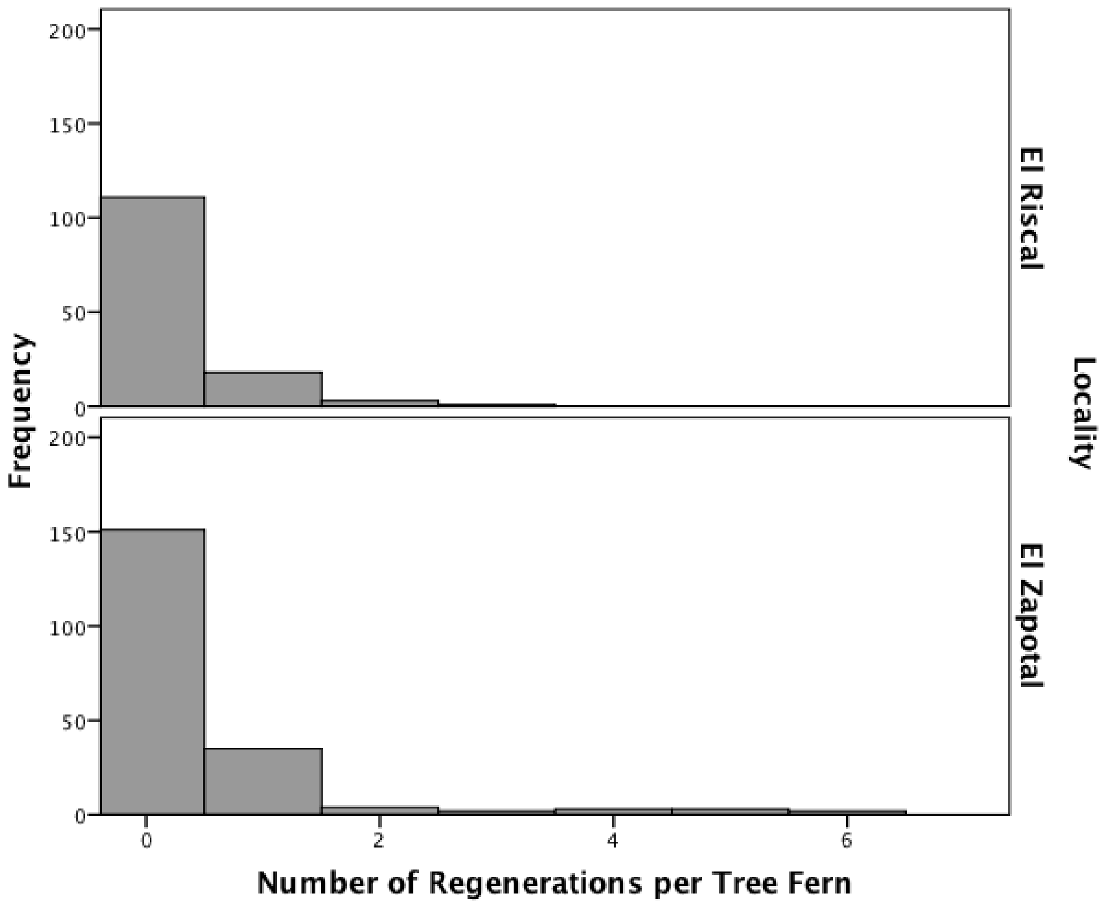

Figure 27: Observed frequency of regenerations per tree fern by locality (all species)

Asophila firma and *Asophila tryoniana* were the only species with sufficient sample sizes to test for differences in regeneration rates according to species. No significant differences were found in the frequency of tree ferns with regenerations between *Asophila firma* and *Asophila tryoniana* (Pearson chi-square = 1.673) (Table 7). Future study should compare regeneration rates among species in the *Alsophila* genus with those of other tree fern genera and families.

Table 7: Observed and expected number of regenerations according to tree fern species. Expected values in parentheses. P > 0.05

Species	**Regenerations absent**	**Regenerations present**
Asophila firma	198 (200.6)	63 (60.4)
Asophila tryoniana	21 (18.4)	3 (5.6)

Significant differences were present in the proportion of regenerated tree ferns between the two study localities, El Riscal and El Zapotal, with a greater than expected number of regenerations present at El Zapotal (Pearson chi-square = 4.934, P = 0.026) (Table 8). This is likely due to the more intensive history of *maquique* harvesting at El Zapotal and may also be related to the higher proportion of dead tree ferns at El Zapotal.

Table 8: Observed and expected number of regenerations according to locality. Expected values in parentheses. $P = 0.026$

Species	**Regenerations absent**	**Regenerations present**
El Riscal	107 (99.1)	22 (29.9)
El Zapotal	112 (119.9)	44 (36.1)

Tree fern diameter was similar with respect to presence/absence of regenerations (t = 0.266, 331 df) (Figure 28). Tree ferns with *maquique* were significantly larger in diameter than those without it (t = -4.799, 331 df, P < 0.001). The average diameter (± 1SE) for tree ferns with *maquique* was 17.9 ± 0.6 cm compared with 14.0 ± 0.5 cm in ferns without it (Figure 29). Younger ferns are smaller and have not yet developed *maquique*.

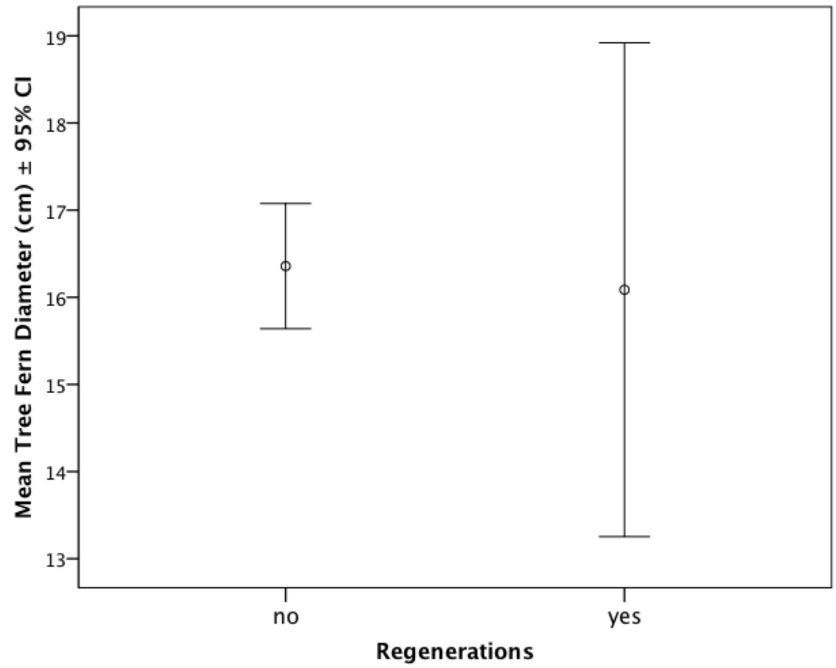

Figure 28: Mean tree fern diameter according to presence of regenerations

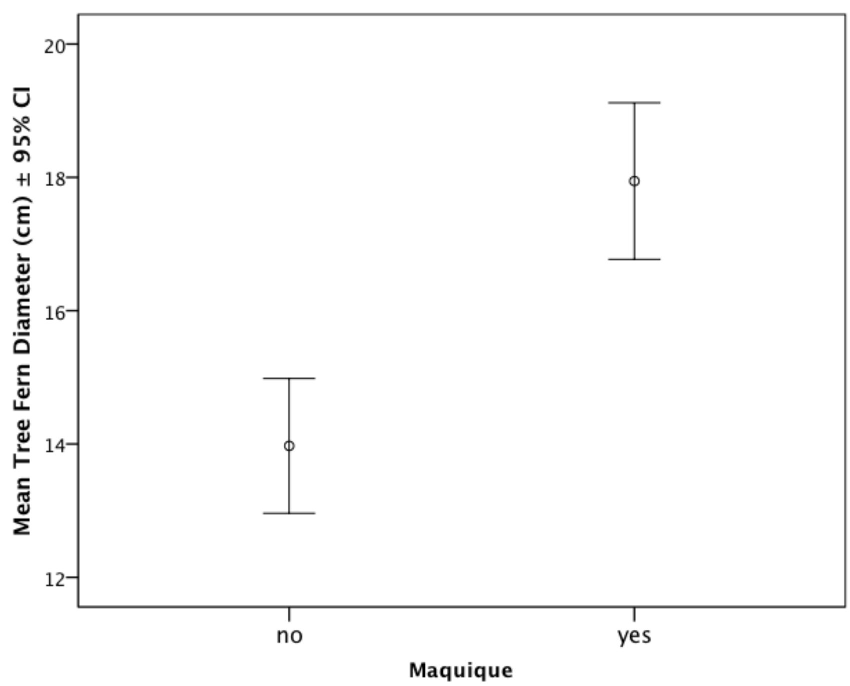

Figure 29: Mean tree fern diameter according to presence of *maquique*

Tree ferns without regenerations were significantly taller than those with regenerations ($t = 2.519$, 331 df, $P = 0.012$) (Figure 30). The average height (± 1SE) for tree ferns without regenerations was 5.0 ± 0.16 m compared with 4.13 ± 0.34 m in ferns with them. This is because ferns with regenerations have been cut. Using linear regression, no relationships were found between tree fern diameter or height according to minimum distance to trails or rivers. Such relationships were absent at the site level, as well.

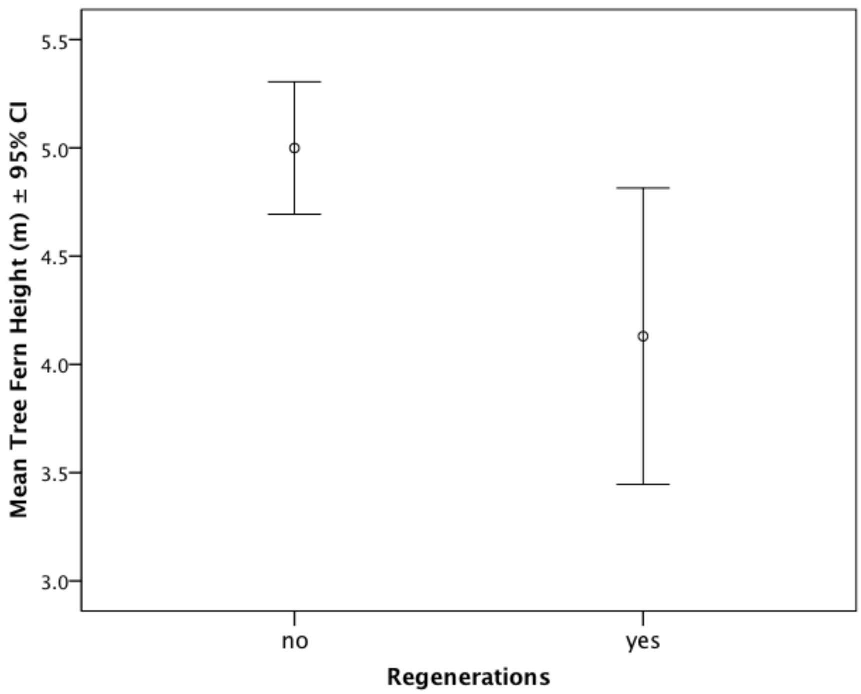

Figure 30: Mean tree fern height according to presence of regenerations

Tree ferns forming *maquique* were taller on average than those without *maquique* ($t = -2.749$, 331 df, $P = 0.006$) (Figure 31). The average height (± 1SE) for tree ferns with *maquique* was 5.14 ± 0.18 m compared with 4.34 ± 0.23 m in ferns without it. This is because ferns develop *maquique* as they grow. Younger ferns are shorter and have not yet developed it.

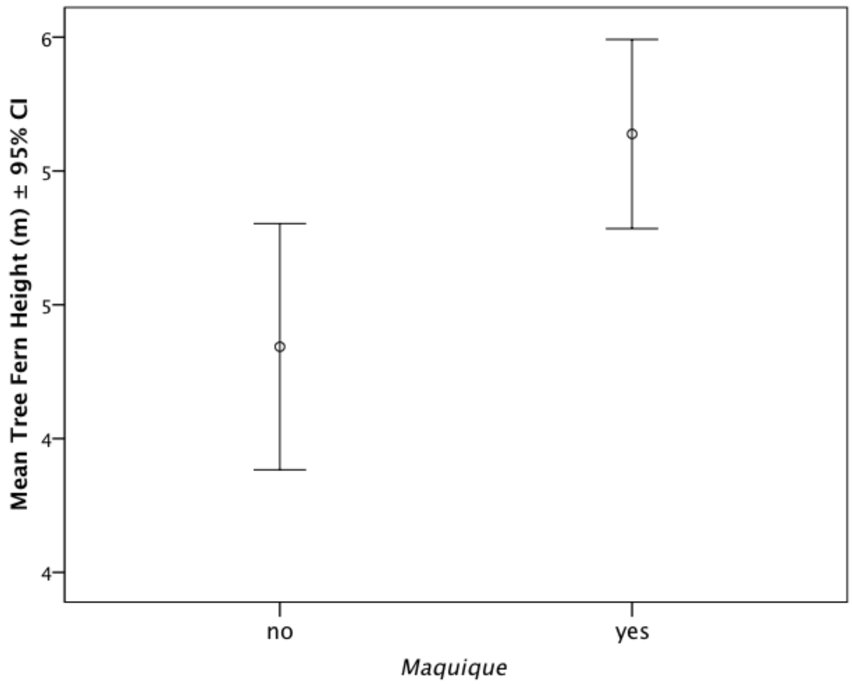

Figure 31: Mean tree fern height according to presence of *maquique*

Despite the hypothesized relationship between *maquique* harvest and tree fern regenerations, there was no difference in the proportion of tree ferns with regenerations according to *maquique* presence (Pearson chi-square = 2.826) (Table 9). This may be because of the small proportion of tree ferns with regenerations present in general (Figure 27). For tree ferns with regenerations present, however, there was a significant difference in number of regenerations according to *maquique* presence (t = -2.990, 331 df, P = 0.003) (Figure 32). The average number of regenerations (± 1SE) for tree ferns with *maquique* was 0.47 ± 0.08 compared with 0.17 ± 0.03 in ferns without it. Tree ferns without *maquique* present that have regenerated were those that had been entirely cut off "through and through" at the base, as opposed to those with the "C" cut. This suggests that the "C" cut may result in a greater number of regenerations than the "through and through" cut. It may also simply suggest that tree ferns with "C" cuts have been harvested repeatedly, producing multiple regenerations.

Table 9: Observed and expected number of regenerations according to *maquique* presence. Expected values in parentheses. $P > 0.05$

Species	Regenerations absent	Regenerations present
Maquique absent	114 (107.7)	24 (30.3)
Maquique present	146 (152.3)	49 (42.7)

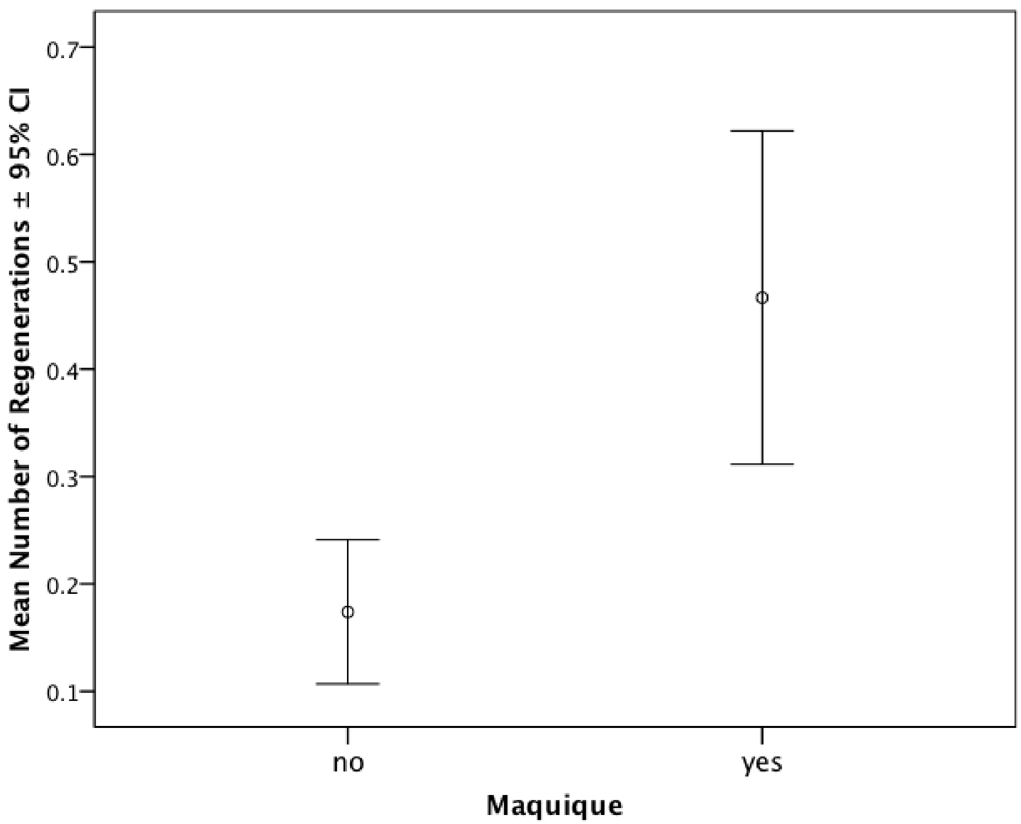

Figure 32: Mean number of regenerations per tree fern according to *maquique* presence

RELATIONSHIPS BETWEEN TREE FERN PROPERTIES AND PROXIMITY TO ACCESS POINTS

A significant difference in distance from tree ferns to trails existed between locations, with tree ferns in El Riscal being closer on average to points of access than in El Zapotal ($t = 9.602$, 331 df, $P < 0.001$) (Figure 33). Tree fern distance to rivers was also significantly different between locations, but with tree ferns in El Zapotal being closer to rivers than those in El Riscal ($t = -9.100$, 331 df, $P < 0.001$) (Figure 34). These differences are due simply to differences in the geography of the two sites. When the minimum distance to a point of access (trail, river, or road) was calculated for each tree fern, it was again significant between locations, with minimum distance to access points being less at El Riscal ($t = 10.933$, 331 df, $P < 0.001$) (Figure 35).

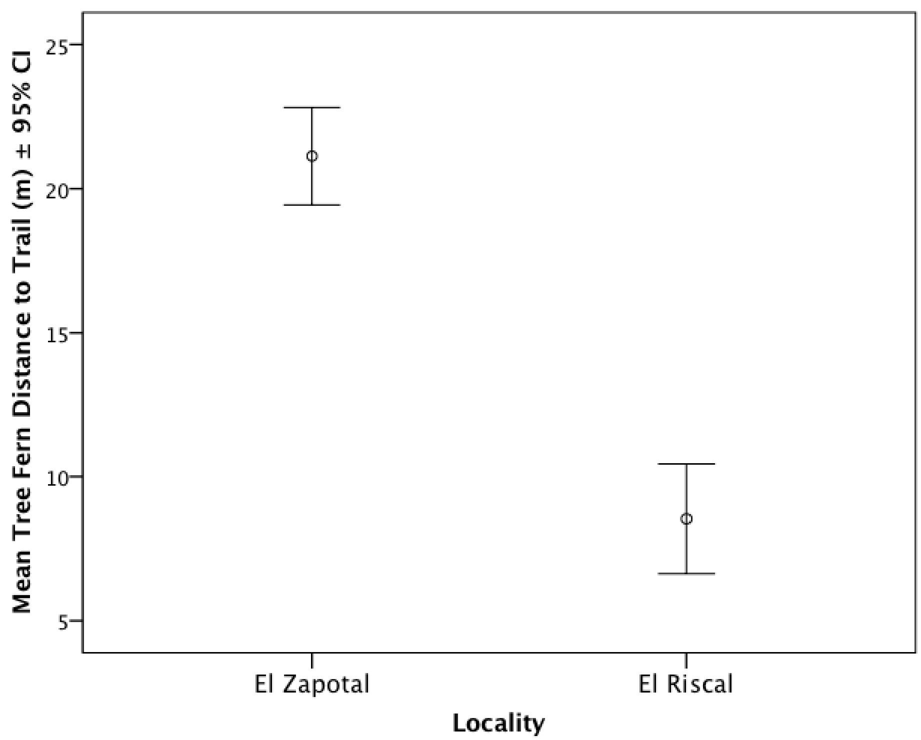

Figure 33: Mean tree fern distance to trail by location

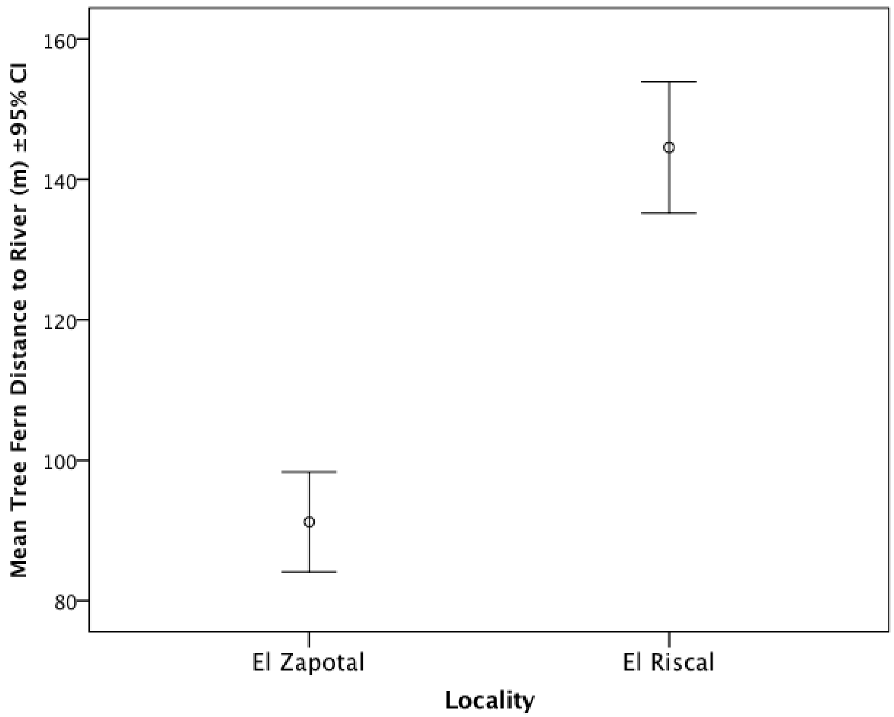

Figure 34: Mean tree fern distance to river by location

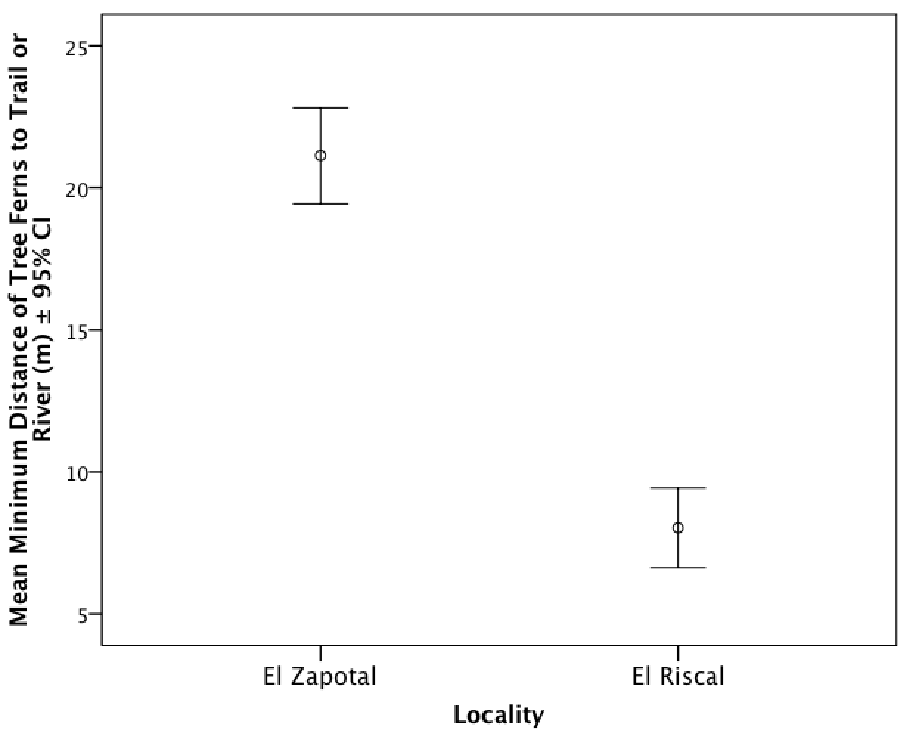

Figure 35: Mean minimum distance of tree ferns to nearest point of access (trail or river)

For El Zapotal, the distance of tree ferns to points of access utilized by harvesters such as trails or rivers was similar with respect to presence/absence of regenerations ($t = 0.908$, 198 df). In other words, the distribution of distances to trails or rivers of tree ferns with regenerations was similar to that of tree ferns without regenerations. However, at El Riscal, this relationship was significant ($t = 2.476$, 131 df, $P = 0.015$) (Figure 36). There, the mean distance (± 1SE) to points of access for tree ferns with regenerations (4.1 ± 1.2 m) was significantly less than that of tree ferns without regenerations (8.6 ± 0.8 m). There were insufficient individuals in either sample with multiple regenerations present to determine whether a relationship exists between number of regenerations and minimum distance to points of access.

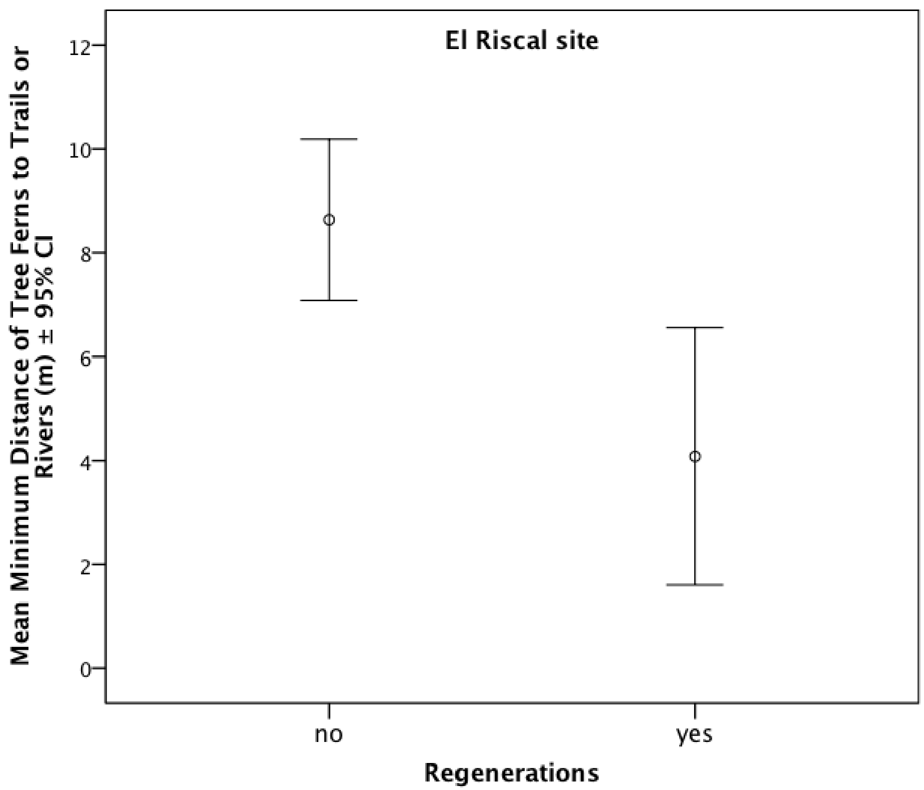

Figure 36: Mean minimum distance of tree ferns to points of access (trails or rivers) according to presence of regenerations at El Riscal

There was no significant difference in mean distance of dead or alive tree ferns to nearest point of access (trail or river) in El Zapotal ($t = -0.592$, 269 df), but in El Riscal, the mean distance of dead tree ferns to trails or rivers was significantly less than that of living ones (Mann Whitney test, $P < 0.002$) (Figure 37). Despite El Riscal being conserved, sporadic incursions by tree fern harvesters have appeared to target tree ferns on the edge of trails, as expected. In El Zapotal, where past tree fern harvesting was carried out primarily by the owner (with incursions by thiefs, as well), ferns may have been selected for harvest for reasons other than proximity to access points, such as size of the fern.

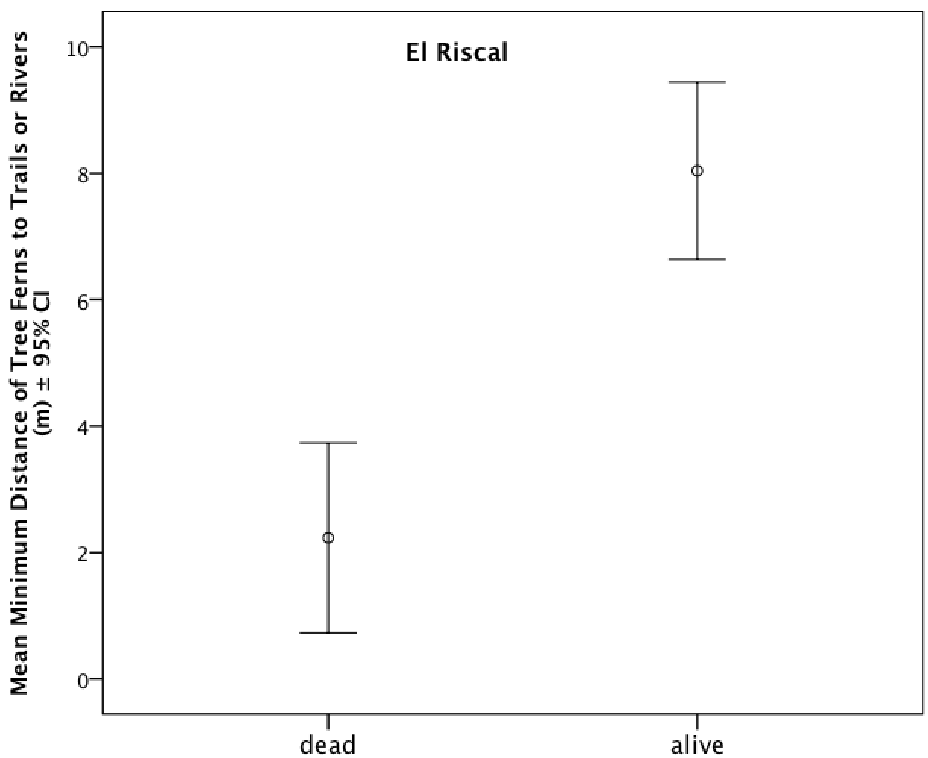

Figure 37: Mean minimum distance of tree ferns to trails or rivers of dead and alive tree ferns at El Riscal (Mann Whitney test)

Chapter 7: Conclusions and Recommendations

Despite claims in the literature that forest clearing and agricultural land use result in the decline of tree fern populations (Lyndenmayer and Ough, 2006), the results from this study indicate that in El Zapotal, tree ferns have continued to thrive in a highly disturbed landscape. Landowners in this community have chosen to protect tree ferns during the forest clearing process, evidenced by the presence of tree ferns along roadsides, in bean fields, and in the middle of pine plantations, as well as other managed environments. Furthermore, the tree fern population in the parcel that was studied show robust recruitment of new plantlets similar to the more conserved forest at El Riscal. This indicates that tree ferns can continue to thrive even in areas under intensive land use, in large part because of the interest of landowners in conserving them as aesthetic and potential economic resources. The conservation of tree ferns in El Zapotal is intentional.

Tree fern conservation in this community seems to have been influenced by messages from government and non-governmental programs in the region, such as national and regional Payment for Environmental Services (PES) programs and Eco-tourism development by a local NGO (Paré *et al* 2008). These programs have highlighted tree ferns as endangered species and a symbol for conservation, reinforcing the idea of forest conservation in El Zapotal. For example, local boys mentioned with pride having rescuing tree ferns that had fallen over in a heavy storm and replanting them because they knew they were important plants (Figure 38).

Figure 38: Children at El Zapotal with a tree fern (Alsophila forma) they had rescued and replanted from a felled caudex. Note the regeneration.

The results from El Riscal regarding the distribution of dead tree ferns and tree ferns with regenerations following harvesting support the hypothesis that *maquique* harvesters operating clandestinely are more likely to target tree ferns with *maquique* closer to points of access (trails or rivers). Tree fern size, in terms of diameter or height, is less significant for these harvesters than accessibility. In the long run, this pattern of tree fern harvesting could modify the distribution of tree ferns as they are displaced from areas closer to human access, despite the ability of some tree fern species to regenerate in highly disturbed environments.

The observation of resprouted tree fern from felled and severed caudexes, "C" cuts and the formation of caulescences occurred primarily in the species *Alsophila firma*; however, a statistical difference among species in resprouting rates could not be determined based on the limited number of observations of other tree fern species in the two study sites. Nevertheless, the presence of this phenomenon of regeneration contradicts the predominant idea that the Mexican species of tree ferns will not regenerate after being damaged during *maquique* extraction (Palacios-Ríos 2002 *pers.com.*, Palacios-Ríos 2005 *pers.com.*, Palacios-Ríos 2006a *pers.com.*, Palacios-Ríos 2006b *pers.com.*). Further study of the regeneration phenomenon is warranted. For example, tree ferns with recent *maquique* cuts should be monitored to evaluate in what percentage of cases regeneration occurs, in what form, and at what rates. Whether this phenomenon occurs primarily in *Alsophila* species, or also in other species, should also be determined. Observations from this study indicate that both *maquique* harvesting and regeneration occurs primarily in *Alsophila firma*, but this species was also the dominant species in both study sites. Further research is needed to determine the sustainability of *maquique* extraction in *Alsophila firma* given its ability to regenerate.

The discovery of tree fern regenerative properties offers potential for the management of certain tree fern species as umbrella species for TMCF conservation in central Veracruz. It suggests that *maquique* harvesting might be sustainable as an NTFP under careful management and government regulation based on scientific data.

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Vita

Othoniel Vázquez Domínguez was born in the city port of Veracruz, Veracruz, Mexico in 1978 where he spent his childhood. Growing up surrounded by the coastal and mountainous landscapes of his home state he became interested in Nature. In 1996 he graduated from high school with a technical degree in Acuaculture, Fisheries and Coastal Environments. He continued his studies in Biology at the Universidad Veracruzana from which he graduated in 2000. From 2004 to 2008 he worked for different state and federal environmental agencies in Mexico including the Secretaría de Medio Ambiente y Recursos Nturales (SEMARNAT), the Consejo Estatal de Protección al Ambiente (COEPA), the Dirección General de Desarrollo Forestal/Secretaría de Agricultura, Ganadería, Pesca y Alimentación (SEDARPA) and the Gerencia Regional X Golfo-Centro/Comisión Nacional Forestal (CONAFOR). He entered the Graduate Program at the Department of Geography and the Environment at The University of Texas at Austin in 2009.

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